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METEORS AND SPACE-TRAVEL*

(Being a supplement to Mr. Clarke's article in the July, 1949, *Journal*.)

By Ing. Guido von Pirquet

The interesting and valuable article by Mr. A. C. Clarke on "Meteors as a danger to space-flight," has suggested several other ideas and conclusions to me, which I will briefly put forward in this note, and which are also very instructive for various cases of space-travel. Before discussing this theme, however, I would like to consider a subject which, although it has nothing to do with astronautics, deals with a very similar problem and so enables us to test the methods we will use later.

An Aircraft Flying Through Rain

A moderately strong shower in our latitudes produces in an hour some 30 mm. or the equivalent of 30 litres of water per square metre per hour. For a medium velocity of descent of the drops of about 3 metres a second, this means a content of about 3 grams of raindrops per cubic metre of air. (I have used quite "rounded-off" figures throughout these calculations, as only approximate results are required.)

Now an aeroplane with a velocity of, for example, 100 m/s will fly through a space of 100 cubic metres per square metre of frontal area and will therefore be bombarded with 300 grams of raindrops a second—or about 1 tonne an hour, which is a surprisingly large value.

Space-rockets and Space-stations in Showers of Cosmic Dust

For the assessment of the limiting value of the dangerous particle size we must make a number of assumptions. A space-rocket might have a frontal area of some 100 square metres. Its velocity in space will not be materially different from that of the Earth and can therefore be taken as about 30 km/s. Thus in about 5 minutes it traverses a space of 1 cubic kilometre, in which there is a mass of about 10^{-9} grams of cosmic dust.

I also assume that a suitable shielding of 3–5 mm. of Duralumin or the like sustains damage from a rifle-bullet which, though repairable, will nevertheless be troublesome. On the basis of constructional stability we can scarcely take a smaller value for the sheet thickness. Even for a diameter of 3 metres and 10 metres length, this corresponds to a weight of only about 1,000 kg.

Now the ratio of velocities for rocket and rifle bullet is

$$Q_v = \frac{30{,}000 \text{ to } 60{,}000 \text{ m/s}}{600 \text{ m/s}} = 50 \text{ to } 100$$

and therefore the ratio of the energies is

$$Q_{en} = Q_v^2 = 2{,}500 \text{ to } 10{,}000$$

* From a translation by G. V. E. Thompson.

Thus for the dangerous limit we must take a mass of 0·01–0·001 gram,* which corresponds to a visual magnitude for the meteor of 5 to 6 in Table I (Clarke's paper). These simply-obtained values agree sufficiently well with Grimminger's estimates.

If we read Table II in Clarke's paper, we find for the 6th and 5th magnitudes the following statements:

Average interval between hits for 5th mag. $\simeq$ 200 years

" " " " " 6th mag. $\simeq$ 100 "

Since we are dealing with limiting values, *i.e.* with hits which are by no means catastrophic, but in fact rather easily repairable, we can see that *the danger for space-travel through meteorites, etc., is negligible*, and that the numerous exaggerated accidents in novels due to meteor showers belong simply to the realm of fantasy—and fantasy, moreover, which is damaging to astronautics.

Interstellar Rockets with Atomic Fuel

This, of course, is the great ideal of cosmonautics. For it we should need a velocity of at least 100,000 km/s—a third of the velocity of light. With such a rocket we should be able to make the round trip to the double star Alpha Centauri in 30 years.

Assuming a frontal area of 100 square metres, the rocket would traverse in a second 10 cubic kilometres of space, and hence would collide with about 10^{-8} grams of cosmic dust—or 10^{-3} grams per day. Now the velocity ratio Q_v, compared with the ordinary rocket, would be $100{,}000/30 \simeq 3{,}000$. Hence the energy ratio ($= Q_v^2$) would be about 10^7, and thus the limiting masses would be 10^{-10} to 10^{-9} grams.

The velocity quotient of 3,000 shows that our interstellar rocket in one second passes through a space 3,000 times that traversed by an ordinary rocket. Thus we can use the existing table (Table II of Clarke's article), simply altering "Hits per hour" to read "Hits per second."

We must next consider the energy quotient, from which we deduce that the mass of the dangerous size is 10^7 smaller than for the interplanetary case. For masses of 10^{-10} and 10^{-9} grams, the diameters will be about 0·01 mm. to 10 microns.

This will correspond to a magnitude of 22, and from Table II by extrapolation we obtain the result:

Mean value for this particle size (mag. 22) = 3 hits per second—a value which would certainly exceed the ability for rapid repairs!

Even if the rocket was covered with armour which could withstand hits of the 22nd magnitude, it would still be destroyed by the far larger (if far rarer) hits of, *e.g.* 14th magnitude (3 hits per hour) or even zero magnitude (3 hits per year).

We see, therefore, that because of the existence of cosmic dust the interstellar rocket is completely impracticable, even if other and more important considerations did not prevent its realisation.

* *Translator's Note:* Mass of rifle bullet = 150 to 220 grains or 10 to 14 grams, therefore mass of meteorite = (Mass of bullet)/Q_{en} = (10 to 14)/(2,500 to 10,000) = 0·006 to 0·001.

INITIAL OBJECTIVES IN ASTRONAUTICS

By Kenneth W. Gatland, Alan E. Dixon and Anthony M. Kunesch*

A paper read to the British Interplanetary Society in London, on January 7, 1950.

Introductory

The development of rockets in the last decade has already increased the altitude reached by instrument-carrying devices from 25 to 250 miles. As performances improve, so we may expect to see the appearance of the close-orbit Earth satellite vehicle,[1] the extra-terrestrial instrument vehicle and the manned research rocket.[2] From these various projects, the interplanetary rocket will arise in the normal course of evolution, as the climax of a long series of experiments rather than a single "do or die" attempt to navigate moonwards. The fact that this process may occupy half a century should not, however, discourage us from considering preliminary objectives of great practical importance, such as the establishment of instrument-carrying rockets in close-orbits around the Earth.

The programme in America to develop such vehicles was initiated in 1946, after examination had been made at Peenemunde and other rocket research centres throughout Germany, of reports and design recommendations, and through the interrogation of prominent technicians by United States and British intelligence teams.

The A.9/A.10 Project

One of the more interesting design studies found in Germany was, of course, the A.9/A.10 project (fig. 1), in which it was sought to extend the range of a modified, winged, A.4 to the Atlantic seaboard of the United States. This was to be achieved by providing the rocket with a 68-ton booster, intended to reach the "all-burnt" condition at an altitude of 80,000 ft. and give the A.9 a starting velocity of approximately 3,900 ft./sec. (table 1). After the booster had jettisoned, the winged rocket, continuing the climb, would reach a final velocity of 9,200 ft./sec. and, being then in highly rarified atmosphere, the missile would follow a ballistic curve. Returning to denser air, aerodynamic controls would terminate the dive at a height of 28 miles. The velocity would then have risen to almost 11,750 ft./sec. and, with this large amount of kinetic energy to dissipate, the estimated gliding range of 3,000 miles for A.9 can easily be believed.

The first example of A.9 differed considerably from the final project, being a straightforward adaptation of the A.4 rocket with swept-back wings. Preliminary work on the application of wings to rockets had previously been carried out with A.5, the small prototype of A.4 (25 ft. long), which developed a thrust of 3,300 lbs. for 45 secs.

Only one or two examples of the winged A.4 were produced and due to serious stability troubles, the project was passed to the Volkenrode establishment for a detailed aerodynamic study to determine a wing configuration with minimum travel of the centre of pressure over the whole speed range from subsonic to supersonic values.

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TABLE 1
GERMAN A.9/A.10 PROJECTS

(All weights in kgs. or lb.)	A.10		A.9		A.10		A.9	
	Metric	English	Metric	English	Metric	English	Metric	English
Gross Weight	85,320	188,090	16,260	35,850	99,960	220,460	13,000	28,660
Individual Step Weight	69,060	152,240	16,260	35,850	86,960	191,800	13,000	28,660
Main Propellant Weight	50,560	111,470	11,910	26,260	61,940	136,700	8,000 8,750	17,640 19,310†
Structure Weight	17,000	37,470	3,000	6,615	25,020	55,100	3,814 3,064	8,820 6,740†
H_2O_2 and Calcium Permanganate	1,500	330	350	772	Nitrogen pressure feed		186	410
Payload Weight	16,260	35,850	1,000	2,200	13,000	28,660	1,000	2,200
Exhaust flow/sec.	1,012·5*	2,231	125·3*	276	1,237	2,728	118 125	260 276†
Thrust (sea level)	200,000	441,000	25,400	56,000	200,000	441,000	25,000 27,200	55,130 60,000†
Length (Metres/ft.)	20	65·5	14·2	46	?	?	14·0	46
Max. Diameter (Metres/ft.)	4·15	13·5	1·65	5·4	3·5	11·5	1·7	5·56
Span over Fins (Metres/ft.)	9	29·5	?	?	?	?	?	?
Specific Impulse	198*		203*		166		212 218†	
Firing Time (secs.)	50*		95*		50		68† 70	
Structural Factor ϵ = Structure wt. / (Structure wt. + Fuel wt.)	·246		0·197		0·288		0·318 0·256†	
Mass Ratio Mo/Mt	2·56		4·07 = 10·42 Effective		2·63		2·7 = 7·1 Effective† 3·2 = 8·4	
Velocity at "All Burnt" in metres/sec. or ft./sec.	1,200	3,937	2,800	3,200	1,200	3,937	2,800	9,200
Altitude "All Burnt"	24 km.	80,000 ft.	160 km.	100 mls.	24 km.	80,000 ft.	160 km.	100 mls.
Range (kms./miles)	—	—	5,000	3,105	—	—	5,000	3,105

* Figures extrapolated from existing data and in correlation of available information on these two schemes.
† Alternative schemes for A.9.

Finally, a delta-wing layout was suggested as the most suitable for the long-range A.9 and with this it was also planned to use an improved motor and lighter structure. With the change in wing-form, the design of the booster was modified to provide for a turbo-pump fuel feed in place of the nitrogen pressure system, formerly envisaged. The A.10, incidentally, was supposed to be recoverable after use and incorporated air-brakes and parachutes of a special design which would open despite the rarified condition of the atmosphere. Each was to have double panels in its canopy; these were to be inflated by compressed air, so that a kind of semi-rigid parachute formed, which gradually took effect upon the atmosphere, serving as a gentle brake for several miles until the condition of free fall was safely arrested.

The A.9/A.10 project[3] was a fairly advanced conception and had it actually been produced, we might at least have known something about human reactions over a wide range of gravity, for it had been seriously suggested that for test purposes, the A.9 should be provided with a pressure-cabin and pilot and at the end of its flight be landed on a conventional undercarriage. Not only would the pilot experience zero gravitation conditions over the free path of the trajectory but, of course, a severe induced "*g*" during the flattening out of the dive. And added to his discomfort at this period would be a rather warm cabin, arising from skin friction. A maximum local stagnation temperature of 7,000° K. would result at the beginning of the glide which, despite re-radiation, would still be severe.

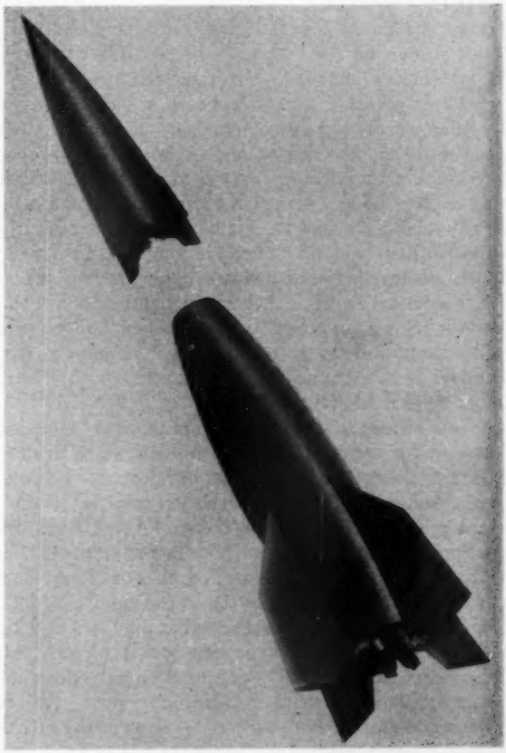


FIG. 1. The German A.9/A.10 project.

A similar, though in some ways even more drastic, technique was suggested by Dr. Saenger[4] in his supersonic-bomber project. Here, the vehicle, returning to denser atmosphere, was literally to bounce on the lower layers of the air and in being thrown upward again to describe a sort of wave-shaped trajectory,

much the same as a flat stone will follow if ricocheted across water. Each plunge into the denser air would result in part of the kinetic energy being consumed, so that the initially long jumps will gradually become shorter, finally to transform into an even gliding flight. Altogether, these proposals appear to exceed to some degree the worse physiological conditions ever considered for *interplanetary flight.*

Orbital Rockets and the Earth Satellite Vehicle Programme

A further proposal attributed to von Braun was for an orbital rocket, to materialise by using a second booster stage behind A.10, thus placing an improved A.9 in a circular orbit at 400 miles altitude. It was this proposal that gave rise in 1945 to the story that Germany was developing a "super-weapon"—the "Space Mirror." The idea—and it was nothing more!—originated from Professor Oberth's studies on the long-term possibilities of space-stations,[5] the uses of which for many purposes, such as refuelling bases, astronomical observatories, and even weather control have often been discussed.[7]

All information on the orbital rocket found in Germany in 1945 was immediately impounded by the Americans and a top-secret project designated PROJECT RAND was initiated with the Douglas Aircraft Company, combining in addition the resources of the Armed Services and certain selected research establishments. Contributing to this endeavour are dozens of high-ranking United States and German scientists, including von Braun.

Although much secrecy surrounds this work, one of its first by-products was a comprehensive theoretical analysis of the nature and extent of the atmosphere. The importance of such an investigation is obvious, for the orbital rocket is effective only if located "outside the atmosphere." Even the slightest trace of air would, of course, have a cumulative drag effect on an orbital missile and cause its ultimate return to Earth.

As is now well understood, the only way of obtaining, by chemical propellants, the velocities needed for escape or orbital missions is by means of the step-rocket, which consists essentially of a series of boosters dropped one after the other as they exhaust their fuel and impart their impulse to the stages ahead. Several important papers on this subject have appeared since 1945,[8,10] particularly Malina and Summerfield's study, in which it was shown that escape velocity can be obtained by guided missiles with any number of the available propellants by proper choice of the number of steps. As an example, a 10-lb. payload could be projected from the Earth by a five-step acid-aniline rocket with a gross mass of 823,000 lbs., or a five-step oxy-hydrogen rocket of only 8,320 lbs. The development of such rockets is clearly one of the next stages in astronomical research, and will enable us to send recording apparatus, and even television equipment, to the Moon and beyond, as well as contributing greatly to the fields of radio research and meteorology.[9]

To obtain these penetrations into space will require not only multiple step-rockets, but even more drastic techniques (such as expendable construction of the individual steps) where the projection of heavier payloads are involved.

Some early thoughts on expendable-construction have already appeared in JOURNAL,[10] but it will be as well to restate the principle.

TABLE 2
3-STEP EXPENDABLE TANK ORBITAL INSTRUMENT ROCKET

VEHICLE	OVERALL PROJECT (including 180 boost rockets)		1ST STEP		2ND STEP		3RD STEP	
	Metric	English	Metric	English	Metric	English	Metric	English
Gross Weight	161,545	356,125	137,000	302,020	9,800	21,610	700	1,540
Weight of Step	24,545	54,110	127,200	280,410	9,100	2,010	650	1,430
Structure wt.	14,303	31,520	22,290	49,140	1,927	4,250	137·6	303
Propellant wt. (including pump fuels)	115,152	253,850	104,910	231,370	7,173	15,810	512·4	1,130
Payload	50	110	9,800	21,610	700	1,540	50	110
Thrust Values	427,400 (at ta	942,200 ke-off)	193,300 t o 211,000	426,130 o 465,150	21,100	46,515	1,500	3,300
Exhaust Flow (per sec.)	2,026·7	4,470	879·2 502·4	1,940 1,110	87·92	194	6·28	13·85
Total Propellant (flow/sec.)	2,059·6	4,540	912·1 521·2	2,010 1,150	91·21	201	6·52	14·37
Estimated Length (metres or ft.)	18·0	59·1	18·0	59·1	9·35	30·7	5·75	18·9
Estimated Diameter (metres or ft.)	4·6	15·1	4·6	15·1	1·85	6·1	0·75	2·5
No. of Expendable Tank Bays	—		3 (Plus 3 motor units)		1		—	
No. of Motors	—		7 (3 jettisoned)		1		1	
Structure Factor $\epsilon = \frac{\text{Structure wt.}}{\text{Structure wt.} + \text{Fuel wt.}}$	—		0·176		0·212		0·212	
Actual Mass Ratio (Mo/Mt)	—		4·2		3·73		3·73	
Effective Mass Ratio	84		5·31		4·25		3·73	
Specific Impulse	—		204 to 240		240		240	
S.I. Inc. Pump Fuels	—		197 to 232		232		232	
Firing Time (secs.)	283		125		79		79	
Characteristic V (km. or ft./sec.) (neglecting "g" and drag)	(Boost Motors) (207 680) 10,297 33,790		3·800	12,470	3·290	10,800	3·000	9,840

Note: Weights given in kgs. and lb.; Dimensions in Metres and feet.

The proposal is to break down the forward portion of the rocket hull into separate tank stages which jettison progressively as propellant is consumed. Each stage consists of two half-cylindrical tank bays with integral structure which, on assembly, form an efficient hull.

The component tanks are locked together with explosive ties and pressure balance is provided between them, allowing the use of light diaphragms for the backing panels. The separate stages have conical noses, both to afford some streamlining effect in the early part of the ascent, and to provide a light method of jointing, since all tanks are faced together. End loads would be transmitted mainly through external jointed longerons to which the tank bays are directly anchored.

It is particularly when we come to consider man-carrying "escape" rockets that the problems become really formidable. However, before going on to discuss this aspect, we would first like to include some results obtained in applying the expendable-tank idea to a rocket to reach a circumterrestrial orbit at a height of between 600 and 700 miles. The rocket envisaged (fig. 2; table 2) was a three-step vehicle with the component rockets situated one within the other. In no case, however, does the design exceed the limitations imposed by current engineering practice, and the propellant is taken as liquid oxygen and alcohol.

FIG. 2. Close-orbit earth satellite vehicle (3 steps + expendable tanks).

We particularly wish to emphasise the conservative nature of this study. It seeks to show that, if ever we are allowed officially to think "big" in terms of rockets here in Britain, we could effectively design useful orbital vehicles with a propulsion unit of no greater efficiency than the existing A.4 motor.

The specific impulse was taken as 204 at sea level, increasing to 240 as the

rocket leaves the denser atmosphere; this, of course, is the figure already obtained in A.4 and *Viking*. A similar ruling was followed in selecting the structural factor. The motors are based on the A.4 propulsion unit, using the same thrust/motor weight ratio; also, the same tank-bay mass ratio as A.4, including all structure, tanks and insulation.

The structural factor thus becomes:—

$$\frac{\text{Structural wt.}}{\text{Structural wt.} + \text{propellant wt.}} = 0{\cdot}212.$$

Finally, in this preliminary analysis, the payload weight was required to give fair scope for useful instrumentation without taking the initial mass to excessive limits. In order to obtain a reasonably accurate compromise, a rough approximation was obtained for several possible projects, and of these a three-step expendable-tank rocket, with a 110 lb. payload, was finally selected.

The ratio $\frac{\text{Initial mass}}{\text{Payload mass}}$ was taken as 14 (that of the A.4 is 13·3 and *Viking*, depending on the payload, 5·7 to 95·1). Therefore, on the basis of a 110 lb. payload the final step has a mass of 1,540 lb., the second step 21,610 lb. and the first, 302,000 lb. The thrusts of the second and final steps were fixed at 46,515 and 3,300 lb. respectively, the acceleration varying between 1 g. and 8·6 g. effective.

The initial step would, of course, be restricted to moderate thrust because of the limitations imposed by the use of the A.4 motor. It was decided, as we have already observed, not to speculate on more powerful rocket motors than already exist, but to utilise seven unmodified A.4 units, each complete with its own pumps and ancillaries. We considered that these seven motors would be mounted in a thrust ring, four retaining their own internal control vanes, these to be aligned to act together.

The arrangement of motors in the first step allows for the acceleration to be held below 5 g. effective by the jettisoning of three motors; this is, of course, for structural reasons, to reduce the very large stresses that would otherwise occur in the structure of the second step if it were to be subjected to high rates of acceleration with propellant tanks full.

It was assumed that solid boost rockets with semi-restricted burning, each giving 5,000 lb. thrust for 5 seconds, would assist at take-off. For these was assumed a sea-level specific impulse of 200.

The solid rockets are mounted in two banks around the base of the initial step, 92 in the first bank and 83 in the second, each bank of rockets being arranged two deep—thrust would be transmitted by the thrust ring for the A.4 motors. To reduce the otherwise considerable impact thrust at take-off, firing of the boost rockets would be staggered over approximately 1½ seconds for each bank. It was assumed that launching would take place from an elevation of 13,000 ft. to reduce the effect of air resistance and to allow for the increase in thrust over the sea-level value.

Air resistance was calculated according to

$$\frac{R^2 \; i \; d \; f \; (v)}{1{\cdot}22} \; k$$

where R^2 = area in cms.^{2}

i = shape coefficient = 1 for 2 calibre radius nose.

d = air density kg/m^3 at any height.

k = calibre coefficient.

Values of i for this project were taken as 1 for the first 50 seconds, increasing to 1·15 as the nose shape alters when tanks are jettisoned. The coefficient k was taken as 0·5, and the values for $f(v)$ were obtained from the Krupp standard tables.[11,12]

The boost rockets impart a velocity of 460 ft./sec. to the vehicle during their overall firing time of 13 secs. The first tank of step 1 is jettisoned after 50 secs. from take-off at a height of 56,000 ft., when the velocity has risen to 1,500 ft./sec.

The synergy curve (taking the rocket from the vertical path into the orbit) is begun after 65 secs.; the altitude is then 82,000 ft. and the velocity 2,160 ft./sec. Jettisoning of the second expendable tank occurs at 82 secs., when the rocket has reached a height of 124,700 ft. and a velocity of 3,200 ft./sec. Finally, in this first stage, the third tank and three complete motor units are dropped; the time from take-off is now 102 sec., the altitude 197,000 ft., and the velocity 5,700 ft./sec.

Propellant in the remaining tank in step 1 is utilised up to 125 secs.; the vehicle will by this time have reached 325,000 ft, and be moving at 8,500 ft./sec. before separation and firing of the second step.

The velocity has increased to 12,500 ft./sec., when the single expendable-tank of the second step is dropped at 138 miles; this step completes its firing 204 secs. after take-off; the velocity will then have risen to 17,400 ft./sec. The altitude is 186 miles and the total distance covered along the path of the trajectory 250 miles.

At this stage, the second step does not jettison, but remains attached to the third whilst travelling along the trajectory under momentum. This is to ensure that the final step will be in proper alignment when it begins firing and it is suggested that the steam generator of the second step pump unit, would continue to produce steam for use in steering jets; these would maintain correct trim during this delicate period of control.

The final step separates approximately 75 secs. before the peak of the trajectory, which lies between 650 and 680 miles.

The total velocity increment of the final step is 9,840 ft./sec., and there will be negligible "g" loss in this stage of the trajectory.

It is of interest to note that reduction of the desired orbital path to 500 miles permits the payload to be increased to 144 lb., or by retaining the original payload, a substantial reduction can be made in the initial take-off mass.

The principal instrumentation controlling the entire vehicle will be situated in the final step; this would ensure that vital equipment is placed as far as possible from the main propulsion units, thus overcoming vibration problems. A weight saving and avoidance of duplication of certain instruments would also be effected. Batteries would be placed in both the first and second steps to reduce the drain that would otherwise occur in the batteries of the final step if these were to be used over the entire thrust period.

The foregoing is not, of course, suggested as a serious design project, for had the task to be tackled on an official level, we would be at liberty to draw upon certain improved parameters. As it is, however, this simple analysis does show a useful order of magnitude. It also serves to confirm certain definite advantages in the use of expendable construction.

Advantages of Expendable Construction

In the conventional rocket, such as A.4 and more significantly with the simple step-rocket, of which the A.4/WAC Corporal is an early example, the payload is carried in the nose of the rocket. The tank structure, therefore, has to support, in addition to its own weight plus that of propellant, the loads induced by the payload which, of course, increase as acceleration increases. However, in the case of the expendable rocket, the payload is supported directly by the motor-thrust mounting and the tank structure has to support merely its own weight plus propellant. In addition, the tanks and supporting structure, which are integral, are jettisoned immediately they are emptied of propellant, thereby eliminating the need for accelerating unnecessary "dead weight" in the individual steps. The mass ratios are improved in this conception by 14 and 18½ per cent. for the second and first steps; this increase will naturally depend on the original mass ratio and cannot be taken as a standard for this type of construction.

Probably the main disadvantage of expendable construction is that the odd-shaped tanks introduce special design problems and increased complexity, whilst in larger rockets there may be difficulty in the transfer of propellant at a high rate from one tank to another and in sealing the large transfer ports effectively as the tanks are jettisoned. These problems, however, although formidable, do not appear to be insuperable and must be reckoned as part of the price we must pay in developing large high-performance rockets.

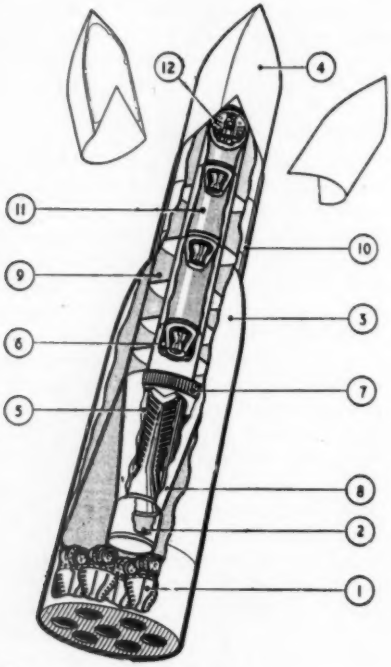
The idea of dropping away large portions of rocket as soon as they become functionally valueless is one of those particular things about astronautics which strikes hard to the man who describes himself as a "practical designing engineer." To the more idealistic rocket designer, however, the whole question boils down to the simple requirement of losing as much structural mass as is practically possible during the period of acceleration.

If this is no "engineer's" solution, it is in any event the best that can be achieved within the range of exhaust velocities that are either attainable now or likely in the foreseeable future. The step-rocket, in one form or another, has undoubtedly come to say for a very considerable time.

The Circum-Lunar Rocket

There is, however, a limit to which the practice can be taken, and that clearly is the jettisoning of steps containing nuclear reactors. For this reason, the conception of our hypothetical atomic-vehicle requires special consideration.

In the popular press, speculation on the possibility of a flight to the moon has been current for many years. Nowhere, however, has there been even an elementary analysis of the structural problem in terms of the enormous rocket vehicles envisaged.



Key to Principal Features:—

(1) Chemical booster—seven motors of 450 tonnes thrust, using liquid oxygen/liquid hydrogen. *Ve* assumed = 4 km./sec.

(2) Fuel for booster pumps.

(3) Expendable tanks for chemical booster (annular type).

(4) Expendable tanks for chemical booster (cylindrical type).

(5) Atomic reactor: 1,100 tonnes thrust, using ammonia propellant. Weight, 40 tonnes. *Ve* assumed = 10 km./sec.

(6) Turbo-pump feed to reactor.

(7) Energy shielding—weight, 20 tonnes; density, 1 tonne per metre.[2]

(8) Gyro-regulated steering jets, incorporating steam exhaust from turbo-pumps.

(9) Expendable tanks for atomic propulsor (annular type).

(10) Jointed main longerons.

(11) Three-step chemical crew rocket, using liquid oxygen/liquid hydrogen. Weight, 60 tonnes, all-up. *Ve* assumed = 4 km./sec. (Serving also as health shielding during operation of atomic reactor—density, 6·25 tonnes per metre.[2])

(12) Pressurised crew chamber. Weight, 1·4 tonnes, including crew, instrumentation, provisions, etc.

FIG. 3. The circum-lunar rocket.

Our object was not to design a "space-ship." That fact will be obvious to anyone who is even remotely connected with engineering, but it is surprising how often such a claim is made by newspaper correspondents in writing up our conclusions. What we have endeavoured to provide in these studies, are merely orders of magnitude which will help us place in a truer perspective certain initial objectives in the development of astronautics, and because the round trip to the Earth's satellite represents the easiest case in the true interplanetary ventures, we chose as our principal subject the *Circum-Lunar Rocket.*

The series of scale-models, exhibited at the Society's Conversazione in October, 1949, was intended to illustrate the main features of such a project:—

(*a*) the application and shielding of a nuclear reactor of certain assumed performance;

(*b*) expendable-construction;

(*c*) the application of Orbital Stage Technique.[7,13]

For reasons which will be explained, the design is represented in three stages: (1) chemical booster, (2) atomic booster, and (3) chemical payload rocket (fig. 3).

In view of the considerable technological development required before such a vehicle is finally possible, it was decided to speculate on certain improved performance characteristics for the chemical rocket systems giving 4 km/sec. *Ve* (13,125 ft./sec.). Our conception of the reactor has been based on the assumption that a nuclear-powered rocket can be developed capable of giving an exhaust velocity of 10 km./sec. (32,800 ft./sec.) with a fairly dense propellant material; it remains to be seen whether such a unit can be devised and constructed. News that Northrop Aircraft Incorporated are making studies of potential materials for use in propulsion reactors, serves as an interesting background to papers by Shepherd and Cleaver,[14,15] who have made well-defined studies on the long-term possibilities of the nuclear power-unit. A graphite-fissile material is assumed to be sectioned up in a kind of honeycomb lattice actually inside the combustion chamber—through it is pumped at high pressure a working fluid, such as ammonia, which expands into the propelling jet. Although such a unit still involves a rocket composed of 70 to 80 per cent. (by weight) of chemical fluid, it holds promise of an exhaust velocity more than double that attainable by the best conventional bi-fuel rocket system we can visualise. Even with these optimistic design parameters, however, we shall see that to achieve the desired performance requires maximum ingenuity in the structural conception.

The proposed function of the three propulsion stages is as follows:—The chemical booster is required to lift the main atomic-propulsion stage clear of the denser part of the atmosphere to reduce the radioactive contamination of the launching site and lower atmosphere and especially to prevent serious blowback effects from the fission products beyond the radiation shadow.

First to jettison are the booster's expendable-tanks, two splitting off from the nose and two from the sides; finally, the booster itself drops away, exposing the nozzle of the atomic reactor. Similar expendable-tanks housing the working fluid jettison from this second stage rocket until, when the atomic power-unit cuts out, the reactor section is discarded; separation is designed to

TABLE 5. CHEMICAL-ATOMIC EXPENDABLE TANK—5-STEP CIRCUM-LUNAR ROCKET

	Overall Project		1st Step (Chemical Booster)		2nd Step (Atomic Booster)		Chemical Payload Rocket							
							Overall		1st Step		2nd Step		3rd Step	
	Metric	English	Metric	English	Metric	English	Metric	English	Metric	English	Metric	English	Metric	English
Gross Mass	1,240	1,220	1,240	1,220	562	553	60	59	60	59	30	29·5	10	9·84
Individual Step wt.	—	—	678	667	502	494	—	—	30	29·5	20	19·7	8·6	8·45
Propellant wt. (including Pump Fuels)	808	795	420	413	347	341	41	40·3	21	20·65	14	13·75	6	5·9
Payload	1,400 kg. (final)	3,085 lb.	562	553	60	59	1,400 kg. (final)	3,085 lb.	30	29·5	10	9·84	1,400 kg.	3,085 lb.
Thrust Values (tonnes/tons)	—	—	"Take-off" 2,830 "All burnt" 3,150	2,780 3,100	1,100	1,082	—	—	200	196·5	75	73·7	25	24·6
Exhaust flow/sec. (kg. or lb.)	—	—	7,764	17,100	1,079·5	2,380	—	—	491	1,082	184	406	61·4	135
Total Propellant Flow in kg. or lb./sec. (including Pump Fuels)	—	—	8,000	17,640	1,106·8	2,440	—	—	506	1,115	190	419	63·3	139·5
Volume of Propellant Flow (metres³ or ft.³/sec.)	—	—	32·5	1,150	1·623	57·5	—	—	2·06	73	0·75	27·4	0·26	9·1
Power required for Pumping—*32 kg./cm² for Chemical Motors and 70 kg./cm² for Reactor (at 85% efficiency)	—	—	115,800 kw.	155,200 b.h.p.	12,600 kw.	16,900 b.h.p.	—	—	7,350	9,850	2,750	3,690	920	1,230
Estimated Length (metres/ft.)	58	190	58	190	37	121·4	19·5	64	—	—	—	—	—	—
Estimated Diameter (metres/ft.)	10	32·8	10	32·8	7	23	3·5	11·5	3·5	11·5	3·5	11·5	3·5	11·5
No. of Motors	—	—	7		1		3		1		1		1	
No. of Expendable Tanks	—		Single-step 2 Tank Bays		Single-step 7 Tank Bays		3-step		—		—		—	
Specific Impulse	—		407		1,020		407		407		407		407	
S.I. inc. Pump Fuels	—		394		995		394		394		394		394	
Approx. Firing Time—secs.	607 to 627		52		330		225 to 245		45 to 50		80 to 85		100 to 110	
Structural Factor $\epsilon = \frac{\text{Structure wt.}}{\text{Structure wt.} + \text{Fuel wt.}}$	—		0·382		0·306		—		0·30		0·30		0·30	
Actual Mass Ratio (Mo/Mt	—		1·51		2·62		3·16		1·54		1·87		2·5	
Effective Mass Ratio	—		1·55		2·94		7·2		—		—		—	
Characteristic V., neglecting effect of "g" and Drag (kms. or ft./sec.)	19·83	65,040	1·69	5,540	10·52	43,500	7·62	25,000	1·68	5,510	2·41	7,900	3·53	11,590

* 455 and 995 lb./in.² *Note:* All weights in tonnes/tons, except where stated.

occur at orbital velocity several hundred miles from the surface so that it remains out in space circling the earth. The final three-step chemical rocket, containing the crew, completes the mission. In effect, the atomic rocket is a second-stage booster and the propellant in the chemical payload rocket, containing the life-compartment in the nose, has the useful advantage of shielding the occupants from all harmful radiation emitted by the reactor.

This preliminary conception will serve to indicate the main features which, at this early stage, it appears will be involved in harnessing nuclear energy for propulsion. The results of the study are summarised in table 3.

Launching of the Circum-Lunar Rocket was assumed at an elevation of 13,000 ft.; the chemical booster would impart a velocity of 3,100 ft./sec. to the atomic stage, completing its firing at an altitude of 75,000 feet. The booster section is then jettisoned and to effect adequate clearance from the atomic-stage when the reactor comes into operation, it must be retarded for a few secs., perhaps by directing the remaining pump fuel through forward-firing jets; this in conjunction with the time lag of 15 to 20 secs. between separation and starting of the reactor allows for a distance of 1,000 ft. between the two components. Thus we ensure freedom from possible blowback of radio-active gases beyond the radiation shadow.

The atomic stage commences firing at a height of 131,000 ft., the velocity at this point is 2,460 ft./sec., the loss due to gravity and drag amounting to 640 ft./sec. The vehicle will then start the turn to bring the trajectory to the desired orbital height. A velocity of 17,400 ft./sec. is reached approximately 295 secs. after take-off, whereon the reactor is closed down. The step would continue in free-flight until just before the peak of the trajectory, when the reactor will be restarted to match the speed of the vehicle to orbital velocity.

Having layed off the atomic reactor in a circular orbit, the final payload rocket is free to complete the mission. This rocket consists of three chemical steps carrying a useful payload of 3,085 lb. This three-step vehicle has an effective velocity of 25,920 ft./sec.; this is sufficient to permit acceleration from orbital velocity to escape velocity, breaking into the circum-lunar orbit, finally effecting return to a circum-terrestrial close-orbit. An allowance of 5,900 ft./sec. has been made for safety margins, course corrections and to compensate for the losses occurring during starting up and shutting down of the various motors. A secondary vehicle with an effective velocity of between 16,000 to 19,000 ft./sec. would be required to be placed into a matching orbit so that the personnel can be safely retarded back through the atmosphere. It remains to be seen to what extent air-braking can be relied upon to reduce the velocity increment required in returning rocket vehicles from the orbit. The foregoing remarks illustrate the enormous mass requirements that are involved, even assuming the use of atomic energy and every device to improve the structural factor, and it will be evident from our following analysis of the structural aspect that to consider a vehicle much exceeding a gross mass of 1,000 tons, will present formidable design and handling problems.

We therefore come to consider the problems likely to be met in the *construction* of a Circum-Lunar Rocket.

Before the structure of our rocket can be finally settled, it is necessary to

consider the loads acting upon the rocket as a whole. The loads on the structure are the weight of the fuel acting downwards, and the pressure of the fuel acting radially outwards.

It will be realised that the conditions of maximum loading occur at "take-off," when the weight of fuel is greatest. These loads consist of the *end loads* acting *downwards* and the *pressure loads* acting *outwards* on the shell of the vehicle. The maximum stress due to both these forms of loading will occur in the structure surrounding the chemical booster.

From the design point of view, the rocket may be divided into three main sections, these being:—

1. The three-step Chemical Payload Rocket.
2. The tank units for the Atomic Reactor.
3. The outer tanks for the Chemical Booster.

Each section represents a cylinder subjected to internal pressures.

Before we can proceed to design our structure, it is necessary to calculate the pressures and end-loads and draw the load distribution diagrams for each of our separate cylinders of fuel. We shall discuss the characteristics of the loading diagrams as we come to make use of them.

Having drawn our diagrams and obtained some idea of the loading imposed on the structure, not only as to how these loads vary, but also their magnitudes, we can now attempt to design the structure on a strength basis.

Three-step Chemical Rocket

The total weight of this rocket is 59 tons; of this, 40·3 is fuel. The structural weight is then 18·7 tons. Allowing for an acceleration of 3 "*g.*," our structure for the chemical rocket is then subjected to a maximum end-load of 56·1 tons. The three steps are quite separate from each other, and only the loads due to the structure will vary along the full length of the complete rocket.

Our end-load diagram (fig. 4) has two steps which are due to the concentrated weight of the rocket motors and this diagram serves as a good example of the difference between the theoretical triangular distribution of end-load and the more practical distribution as shown.

Each of the three steps has its own radial pressure diagram and this gives rise to the "fir-tree" shape of the diagram.

The diagram has been drawn to depict the load system acting on the rocket when the first step is in operation, the rocket motor being fed from the fuel compartment, which is pressurised to 20 lb./in.^{2} Allowing for the radial pressure due to the weight of the fuel, the total radial pressure acting outwards is then 29 lb./in.^{2}

This step must also be capable of standing up to the end load of 104·8 tons, since it must also support the two remaining steps.

The diameter of the rocket is 11·5 ft., and if we assume the rocket to be a shell with a skin thickness of 0·10 in., this pressure gives us a hoop stress of 19,800 lb./in.^{2} tension. The tensile stress in the skin along the length of the rocket is 9,900 lb./in.^{2} and this "pretension" effect helps to reduce the compressive stress set up in the skin and stringers due to the end load of 104·8 tons.

It would appear therefore that for the chemical step rocket, skin thicknesses of the order of 0·10 in. are necessary.

Since several rocket structures have already been designed and tested, whose load systems compare favourably with the three-step unit considered, we do not anticipate that any real difficulty will be found here.

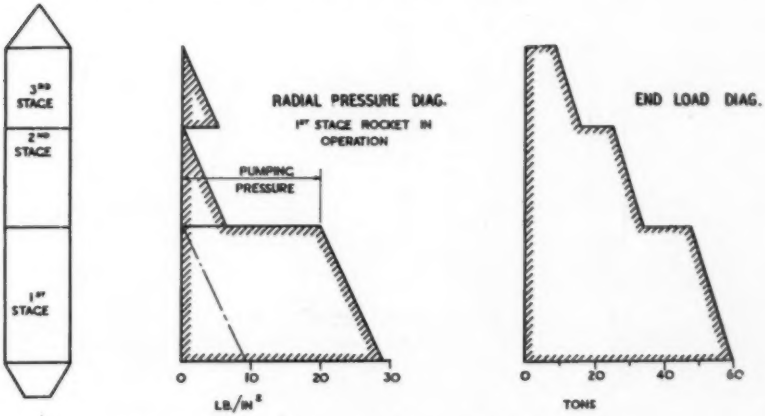


FIG. 4. Loading diagram—3-step chemical payload rocket.

Atomic Rocket Seven-tank Stages

These tanks surround the chemical rocket, and although there are seven tank units, each comprised of two sections fixed together, we may consider them as one cylindrical unit having an inner and outer wall or shell with the fuel in between. We are able to do this, since each tank is connected by a fuel by-pass valve.

The total weight of fuel carried by these tanks is 341 tons and the structural weight assumed for this stage is 153 tons. This structural weight includes fuel valves, release mechanisms for jettisoning the tanks and also the atomic reactor, its shielding (19·7 tons) and its propellant pumps.

Of this total weight only about 27 tons will be actual structural weight of the tanks. At any rate, we shall assume this figure for design purposes. It is in all probability on the high side and in any case is only 7·2 per cent. of the total mass carried by the tanks. The fuel in the tanks develops a maximum pressure on the bottom tank of 17·3 lb./in.^{2} Assuming as before a 3 g. acceleration, we have then a maximum pressure of 52 lb./in.^{2} with an end-load of 81 tons. The weight of the nose-tank (including fuel) is 175 tons and this will be supported by the four main longerons. The weight to be supported is 525 tons or 131·25 tons per longeron; this will develop a compressive stress on each longeron of 2,930 lb./in.^{2}

It has been assumed that the initial tank pressure will be about 60 lb./sq.,^{2} giving a total maximum of 112 lb./in.^{2} (*See* fig. 5.)

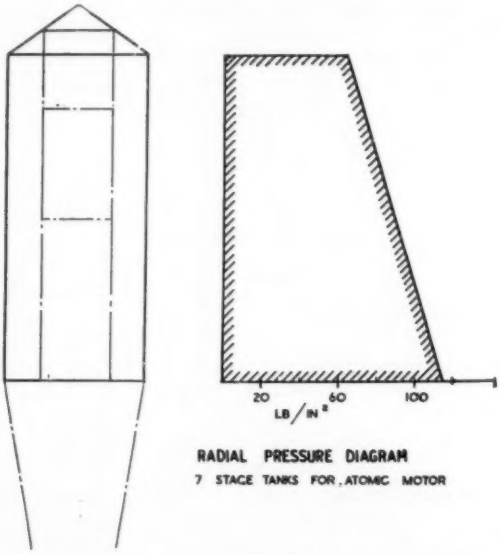


FIG. 5. Pressure loading diagram for 7-stage expendable tanks atomic rocket.

The diameter of the inner shell of these tanks is 11·5 ft., the outside diameter being 23 ft. For the outer skin, the radial pressure of 112 lb./sq.² develops a tensile stress of 30,600 lb./in.² for a skin thickness of 0·50 in., this stress being well within the capabilities of light alloys now in general use.

For the inner skin, the pressure of 112 lb./in.² would develop a compressive stress of 31,000 lb./in.² for a skin thickness of 0·25 in. This stress value is quite out of the question for an unsupported shell of this size, and even if we assumed that as the skin buckles it bears against the shell of the chemical rocket, thereby gaining a relief, such a relief would still not be sufficient, and would only result in the crushing of the walls of the chemical rocket.

The gradual collapse of these two walls would undoubtedly bring about an increase in the resisting pressure of the fuel in the chemical rocket. But such an increase in pressure would cause other sections of the chemical payload rocket to be highly stressed and might not only bring about a complete failure of some other part of the structure, but even cause the chemical rocket to burst. We must therefore look to other means of carrying the load on the inner shell.

To solve the problem of this inner skin we shall transfer the load acting on this skin to the outer skin in the following manner.

A series of vertical baffles arranged radially between the inner and outer skins at 30 degree intervals will be fitted and joined to both inner and outer skins. The long curved panels between these baffles will then be divided by transverse stiffeners, thereby breaking these down into smaller panels, 10 in. × 36 in. We

can then treat them as normal flat panels under pressure. For a skin thickness of 0·30 in., a tensile stress is developed of 30,800 lb./in.^{2} For panels of this type, this is quite acceptable.

We are now left with our vertical baffles acting as tension members between the inner and outer skins of the tank, with a loading system in tension of 4,040 lb. per in. acting towards the centre of the vehicle. If we assume the thickness of these baffles to be 0·10 in., a stress of 40,400 lb./in.^{2} tension is developed. This would be acceptable for a plain sheet of metal, but since holes will be necessary in these baffles to allow the passage of fuel, a baffle of greater thickness will be required; or at least, reinforcing round these holes.

It will be realised that an enormous amount of structure will have to go into these tanks, and bearing in mind that they are expendable, it would appear at first sight that this type of construction is uneconomic.

It should be borne in mind, however, that even without an expendable structure, with the large fuel volumes envisaged, a multiple tank system is still necessary, involving a similar type of construction. It must be remembered that in this analysis we have considered the tank with the highest loads acting upon it, and that the other six tanks will be of lighter construction.

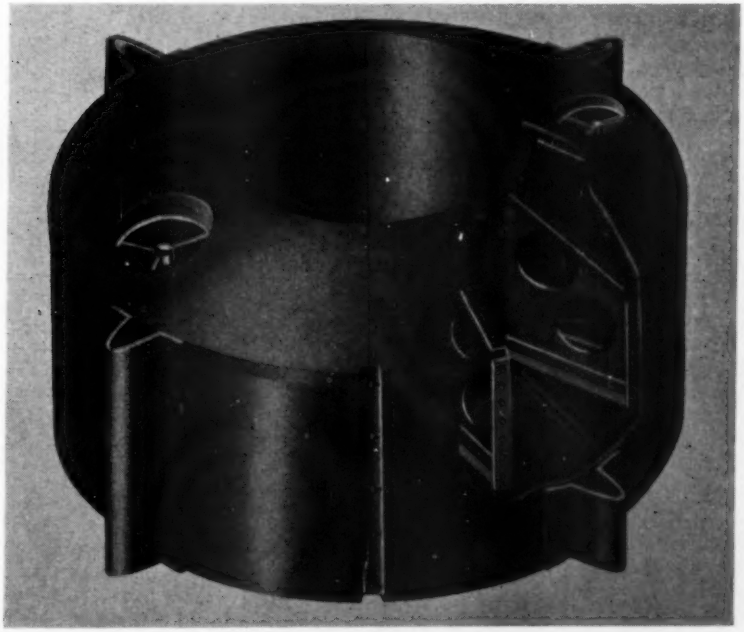


FIG. 6. Impression of a typical expendable-tank bay with radial "load transfer" baffles and external jointed longerons.

An impression of the bottom expendable-tank bay of the atomic rocket, shown in fig. 6, is typical of the type of construction we envisage.

The possibilities of other types of construction are being considered by the authors, and these will be the subject of a supplementary paper.

Assembly of Tanks

The tanks are in two halves and are held together by tie bolts at the joints which carry the skin tension from one half of the tank to the other. The tension in the skin is 15,300 lb. per in. of height at the bottom tank, developed by the internal pressure of 112 lb./in.^{2} Assuming this pressure to act over the full height of the tank, the total tension to be resisted by the tie-bolts is 1,530,000 lb.

In actual fact this tension will vary along the tank stages and at the top tank will be nearly half this value.

We will now consider the tension acting on the bottom tank. The load carried by each tie-bolt will depend on the number of bolts in use on each tank.

As an example, if four bolts are used per side on each tank, the maximum tension in each bolt will be 383,000 lb.

The tie-bolts would fit into recesses in the corner members of each tank, an internally-threaded fitting being provided at each recess.

The bolt itself might have a union body with a central hexagonal shaped centre portion and "handed" threads on the shanks each side. These bolts would have explosive filling and would be detonated immediately the tank-bay emptied, monitored by some form of automatic relay system, thus ensuring that the bolts on each tank bay are exploded simultaneously.

The central body of the tie would be grooved to weaken the bolt, thus ensuring that when the charge is set off it splits at the centre, the force of the explosion also forcing the two tanks apart and throwing them clear of the remaining structure.

We must now consider the problem of designing the tank ends.

The tanks are shaped to facilitate release and, to a limited degree (since the initial jettisoning occurs within appreciably dense atmosphere), to present a fairly streamlined shape. These considerations dictate that the tanks should have conical ends and we have assumed the included angle of the cone to be 110°. Since the tanks fit together, it follows that the lower end of each bay must have an internal cone-shaped end to provide a matching fit on the tank bay immediately beneath it.

During the operation of a typical tank, only the exposed upper end is subjected to pressure, the lower end having a resultant pressure of zero. The pressure acting is the pumping pressure of 60 lb./in.^{2} only, and we arrive at this conclusion in the following manner.

If we consider the loads acting on the tanks at the instant the atomic reactor starts, then from the load diagrams, the pressure distribution from the top tank to the bottom tank is triangular in shape starting from zero at the top of the top tank, and reaching a maximum value at the bottom tank. To these pressures is added the 60 lb./in.^{2} pumping pressure. From this it can be seen that the top tank the only pressure acting is the pumping pressure. At the bottom of the uppermost tank the fuel transfer valves are passing the fuel

continuously into the lower tank, and from this, it will be realised that the pressure at the base of the upper tank is equal to the pressure at the top of the lower tank; hence the no-load conditions.

The conditions are repeated as each tank bay is jettisoned, the revealed upper end of the tank being subjected to the pumping pressure only. In actual fact, there will be a pressure drop across the fuel transfer valves, and the zero loading conditions are not strictly correct; but the loads resulting from this pressure drop are localised about the fuel transfer valves themselves and will be accommodated by local reinforcing.

The angle the conic ends of the tanks make with the centre line of the rocket is 55°, and taking the pressure acting on these ends as 60 lb./in.,^{2} the stress developed is 36,000 lb./in.^{2} tension with a skin thickness of 0·40 in., or, 41,000 lb./in.^{2} for a skin thickness of 0·35 in. Either would be acceptable.

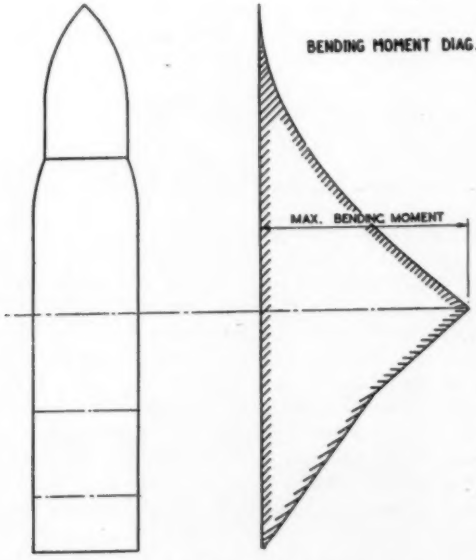


FIG. 7. Bending moment diagram.

During the initial stages of the take-off the rocket may be subjected to bending, due to tilting of the rocket. Although the deviation of the rocket may be only a few degrees, the tremendous weight, and length, will generate very large bending moments on the structure in the region of the centre of gravity.

The magnitude of the bending moment will also depend to some extent on the value of the righting or stabilising force applied by the steering motors. We must also remember that we are applying an acceleration of 3 "*g*."

Calculations show that the bending moment at the centre of gravity for a 6° deviation from the vertical path is in the region of 300×10^6 lb./in. (fig. 7).

It is here that we look to the longeron members for support, and since the large areas of curved skin which constitute the main structure will not resist bending to any degree, these longeron members will be called upon to do practically all the work.

The outside diameter of these tanks is 274 in. and allowing for the depth of the longerons, we may assume that the distance between the longeron centres is approximately 300 in. This gives a maximum possible end-load in the longerons of 1,000,000 lb. The type of longeron visualised has a cross-section similar to a "top-hat" section of the type used for stringers in aircraft, they would, however, be somewhat larger! The depth of the section will be approximately 22 in., the width of the open section being 10 in. with flanges 4·0 in. wide and approximately 0·50 in. mean thickness. The main body of the section will be about 2·0 in. thick and the outside radius at the closed end 3·5 in.

This section gives an area of over 80 in.^{2}, and for an end load of 1,000,000 lb., a stress of 12,500 lb./in.^{2} is developed. This stress would be acceptable in light alloy.

The hollow space inside the longerons might be used for the interconnection of ancillary services.

Since the longerons are broken at each tank bay, a joint and release mechanism must be supplied and this, too, will fit inside the member.

Chemical Booster—Tank System

We will now consider the tanks surrounding the atomic stage which will contain the fuel for the chemical boost rocket. The loading system for these tanks will be identical to those previously considered, namely a triangular distribution of radial pressure; the structural problems are also the same. These tanks consist of a single large bullet-shaped tank bay, and the nose of the vehicle and two further tanks running from the first tank of the seven-stage atomic fuel tanks down to the booster rocket, thus forming a complete sheath around the atomic stage and also forming a streamlined fairing. The lower portion of the fairing tanks also transmit the thrust of the boost motors to the main section of the rocket. It will be realised therefore that the structure of the lower portion of these tanks must be extremely robust, since they have to be capable of transmitting a total thrust at take-off of 2,800 tons.

This thrust will be carried not only by the lower portion of the tanks, but also by additional structure; the latter will serve to transmit the thrust through the radiation shielding and into the base of the chemical payload rocket and the ammonia tanks of the atomic stage.

Before dealing with the method of thrust-load transfer, we shall deal with the upper portion of these side tanks. Although we stated earlier that the type of construction used for these outer tanks must be the same as for the ammonia fuel tanks, this is not quite true for the upper portion. In actual fact we can allow the inner skin to bear on to the outer skin of the ammonia fuel tanks, since the pressure there is greater than the pressure in the outer tanks, and therefore crushing or buckling of the skins cannot occur. We may therefore make this

section of the structure fairly light; in fact, almost flimsy compared with the remainder of our structure. For these outer tanks the maximum radial pressure due to the fuel is 38 lb./in.²

This includes an allowance of 20 lb./in.² pumping pressure and the acceleration of 3 "*g*" previously mentioned.

The diameter of the outer skin is 32·8 ft., and for a skin thickness of 0·40 in., we have a tensile stress of 38,000 lb./in.²

The bullet-shaped nose-tank presents no real problem, and our main concern will not be strength, but how to maintain the shape since this tank will be prone to distortion. However, internal baffles and light metal formers should suffice.

The fuel carried in this top tank would amount to 164 tons, and with a diameter of nearly 23 ft., and an internal pressure of 43 lb./in.² including pumping pressure, we can construct it of light alloy sheet 0·20 in. thick, which will be stressed to 29,500 lb./in.²

We will next consider the attachment structure between the booster rockets and the main structure of the vehicle.

We must remember that our load-carrying structure is also a fuel-carrying structure, and will consist of a single annular-shaped tank, the bottom of which is attached to the booster motors and the top reaching up to the radiation shielding, the whole tank enclosing the atomic reactor.

Since this tank, like all the others, is fitted with baffles of the type already described, we now realise that if we can utilise these baffles to carry the end loads from the booster into the main structure, no further structure is necessary and dead weight is kept to a minimum. If we assume that the load-carrying structure consists of a tank with eight baffles, then the end load per baffle will be 211 tons.

Angle-shaped boom members would be fitted on the baffles at the junctions of the inner and outer skins, and these would form substantial load-carrying members.

These baffles transfer the end-load into three sections of the main structure. One part is the outer fuel tanks containing fuel for the booster rocket; the second part being the continuation of the main longeron members down the side of the atomic reactor. The third part is the structure in the radiation shielding which carries the main weight of the three-step chemical rocket.

In designing this structure it must be remembered that the booster is jettisoned at an early stage and therefore the main fixings between the load transfer members and the main rocket structure must be quick-release joints. This would complicate the design of the main joints, since the conditions laid down indicate that some form of pin-joint will be necessary.

Since explosive bolts, due to their proximity to the main structure, would be out of the question, the only alternative envisaged at the present time is some form of large diameter pin with a suitable withdrawal mechanism.

At the instant the withdrawal mechanism is called upon to operate the pins, a condition of no-load exists throughout the whole transfer structure and the only force against which the mechanism must operate is the friction between the surface of the pins and the joint fittings. It is suggested that some form of

hydraulic or pneumatic system be used, the pressure to operate the jacks coming from storage bottles.

It is essential that each pin-joint have its own withdrawal jack, these being supplied *via* a pressure line from the main source. It would be advisable to have some form of synchronising linkage between the joint pins to ensure that they are withdrawn together, thus making sure that the booster and its structure are released cleanly.

The withdrawal mechanisms and the joint fittings would probably be mounted on a circular reinforcing ring on the atomic reactor and at the radiation shield just forward of the atomic reactor.

The lower ends of the main load-carrying members are attached to the main booster motor structure. This structure might consist of two main circular frames to which the motors and their fuel-feed pumps are attached.

The Pumping Problem

Finally, we must include a note on the propellant feed problems which will be entailed with rocket vehicles of this nature, and particularly in the use of liquid hydrogen. These problems are well illustrated by an analysis of the pumping requirements of the Chemical Booster Step.

The total fuel flow is 17,640 lb./sec. with a volume of 1,150 ft.³/sec., the individual rates being:—

Liquid hydrogen	4,070 lb./sec.
,, oxygen	13,050 ,,
and the pump fuels	520 ,,

The total h.p. required to drive the pumps, assuming that these will operate at 85 per cent. efficiency, would be approximately 155,300 b.h.p. Of this, the hydrogen would account for no less than 125,000 h.p. Of the remaining 30,300 h.p., 24,200 would be absorbed by the oxygen pump and 6,100 in supplying the pump fuels. The pumping pressures for the main propellants have been taken as 455 lb./in.² and for the pump fuels, 995 lb./in.²

Multiple-pump units would be required in handling this power, which might be split up as follows:—14 turbo-pump units of 9,300 h.p. each, to handle the liquid hydrogen. Three units of 8,000 h.p. for the liquid oxygen, and one unit of 7,000 h.p. for the pump fuels.

The volume of flow also presents difficulties, amounting in this case to 1,150 cu. ft./sec.—960 cu. ft./sec. for the liquid hydrogen and 190 cu. ft./sec. for the liquid oxygen.

In our conception, there are 14 turbine units with 28 pumps and feed pipes to handle the hydrogen and each pipe, assuming a flow rate of 30 ft./sec., would have a diameter of 14·5 in. The four remaining turbine units drive eight pumps to pass the oxygen and pump fuels at a rate of 190 cu. ft./sec. and would require eight pipes of 12 in. diameter.

In the case of the Atomic Booster step, the pumping power is required to boost from 60 lb./in.² tank pressure to 995 lb./in.² inlet pressure, with a power requirement of 16,980 h.p.; a convenient division would be: three turbine-pump units of 5,900 h.p. each. The volume flow is approximately 58 cu. ft./sec.,

which could be carried by feed pipes amounting to a cross-section of 2 ft.^{2} for a flow rate of 30 ft./sec.

A weight ratio of 1·23 lb./b.h.p. has been assumed for these turbo-pump units, which is considerably greater than the corresponding figures for the A.4 and Walther pump units, since the turbines would be multi-stage, giving low steam rates. A steam rate of 12·25 lb./b.h.p./hr. has been taken for pumps in the Chemical Booster step and 10 lb./b.h.p./hr. for those in the remaining steps.

Conclusions

It remains now to summarise our conclusions.

On a structural basis, it does not appear that the problems encountered in a project such as we have considered would be beyond solution, even in terms of present-day engineering. There are, however, supplementary problems involved in the construction of a rocket vehicle of 1,000 tons gross mass that would be considerably eased by the use of Orbital Refuelling Techniques.[7,13] It should be emphasised that despite the provision of a nuclear reactor, the all-up weight cannot be materially reduced, especially with a manned rocket. There is still a formidable propellant load in the form of "working fluid" and radiation shielding is itself a large item. The problem of radioactive contamination of the launching site and of the atmosphere, if the reactor were to operate directly from take-off, brings the necessity for a heavy chemical booster.

Other related problems are:—

(1) With expendable construction, that of fuel transfer from tank to tank and the effective sealing of the transfer ports when tanks are jettisoned. The mass-ratio, incidentally, was improved using expendable-tanks, by 3 per cent. for the chemical booster and 12 per cent. for the atomic stage.

(2) There is the mechanical problem of handling hundreds of tons of extremely low boiling-point liquids and the attendant difficulties of fueling a rocket standing 190 ft. high; also insulation problems, which become serious in the case of the final chemical payload rocket, which will require to hold its propellant over a period of time amounting probably to some eight or ten days with a minimum loss.

(3) The steering and control of such large space-vehicles present their special problems, and possible methods are efflux control vanes, pivoting motors and subsidiary steering jets—perhaps a combination of these methods. The control of the vehicle would be by instrumentation contained in the final payload stage, ground monitored, but embodying over-ride controls in the life-compartment.

(4) A serious problem of interest to all but the occupants of the rocket will be the question of jettisoning tanks and steps, which if dropped before orbital velocity, will fall back in a band stretching several thousand miles around the Earth. Indeed, in the case of the final tanks of the atomic-stage, which are dropped at velocities closely approaching orbital velocity, they might easily describe descending orbits encircling the Globe. This danger path, although protracted, will fortunately be fairly narrow and extremely fine control will need to be exercised over the design to ensure that these tanks are dropped at such velocities that, on spiralling back they will fall in unpopulated areas. In

the cases of initial steps and tanks, drogue parachutes might usefully be employed to reduce the impact velocity. These considerations will largely dictate the location of the launching site.

Although it has been stated that the engineering problems involved in such a project are not beyond solution, it can be appreciated that the actual construction would call for jigs and erection plant of mammoth dimensions, the time taken in building being measured in years and requiring a veritable army of civil engineers and technicians. It might be emphasised, in conclusion, that a project of the nature described will come about only after many years of extensive research, the sole aim of which will be to produce such a space-vehicle; indeed, the economic difficulties might well prove to exceed those of design. Such a programme would itself be based upon knowledge already gained in the operation of man-carrying research rockets and earth-monitored extra-terrestrial guided-missiles.

The scale of the undertaking, on a purely scientific basis, might even place the project outside the scope of a single nation, with the possible exception of the United States. But there is still the prospect that interplanetary flight may become the first working basis for full international collaboration. Whether or not the military implications of such an endeavour will preclude this ideal remain to be seen, for it is obvious that a nuclear power-unit capable of producing a moon-flight could equally deposit atomic explosive on the other side of the Earth. In this case, we may find the difficulties of an international space-flight federation as formidable as those which we have already found in the control of atomic energy—when the first interplanetary space-vehicle may develop under the classification "Top Secret," probably in America or possibly (who knows?) in the Soviet Union. Indeed, the "Manhattan Project" of astronautics may be under way on some secluded Pacific Island or behind the impenetrable screen of the Ural Mountains much sooner than most of us expect!

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MINIMAL TRAJECTORIES*

By Derek F. Lawden, M.A.

1. Introduction

It has been shown by the author,[1] that if the object of fuel consumption in a rocket is to develop sufficient momentum in the vehicle to allow it to escape from some gravitational field, the rate of increase of the net energy is greatest if the exhaust is being directed along the tangent to the trajectory, and hence that the fuel consumption necessary to achieve the desired escape velocity is least for a trajectory described under these conditions. It has also been shown that it is desirable, in the interests of fuel economy, to burn fuel at the greatest rate possible at the commencement of the trajectory, the economy being theoretically greatest for instantaneous burning. This paper considers the more difficult problem of the most economical manner in which we may programme the fuel consumption and direct the thrust, in order that the rocket shall describe a trajectory joining two given points A and B, its velocity at these points being prescribed. The problem of the most economical manner of description of a given trajectory, the velocities at the end points being specified, will also be considered for the special case of no gravitational field.

A list of the symbols to be used together with their definitions is set out below. Suffixes zero and unity will be attached to a quantity which is to be calculated at the commencement A, or the termination B, of a trajectory, respectively.

M is the mass of the rocket,

$R = M_o/M_1$, is the mass ratio,

t is the time variable, and $t = o$ at A, and $t = T$ at B,

v is the velocity of the rocket,

U is the exhaust velocity,

(x, y, z) are the co-ordinates of the rocket referred to rectangular cartesian axes,

(l, m, n) are the direction cosines of the exhaust velocity, relative to these axes,

(u, v, w) is the velocity of the rocket,

K is the curvature of the trajectory,

s is the arc length parameter measured along the trajectory, so that $s = o$ at A and $s = S$ at B,

a is the angle between the exhaust velocity and the backward tangent to the trajectory,

V is the potential function of the gravitational field.

2. The General Problem

The equation of motion of a rocket in a gravitational field of potential V is

$$\frac{d\mathbf{v}}{dt} - \frac{\mathbf{U}}{M}\frac{dM}{dt} = -\operatorname{grad} V. \quad \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

* This paper should be compared with that by G. F. Forbes in the March, 1950, *Journal*, pp. 75–9.—Ed.

Resolving this equation along the directions of rectangular cartesian axes, we obtain after rearrangement, the equations

$$\left.\begin{aligned} \ddot{x} + \partial V/\partial x &= -\frac{lU}{M}\frac{dM}{dt} \\ \ddot{y} + \partial V/\partial y &= -\frac{mU}{M}\frac{dM}{dt} \\ \ddot{z} + \partial V/\partial z &= -\frac{nU}{M}\frac{dM}{dt} \end{aligned}\right\} \quad \text{.....(ii)}$$

where the dots denote differentiations with respect to the time.

The identity $l^2 + m^2 + n^2 = 1$ implies

$$\left(\frac{U}{M}\frac{dM}{dt}\right)^2 = \sum_{x,\,y,\,z}\left(\ddot{x} + \frac{\partial V}{\partial x}\right)^2$$

and by taking the square root and integrating we find that

$$U \log R = \int_0^T \left\{ \Sigma\left(\ddot{x} + \frac{\partial V}{\partial x}\right)^2 \right\}^{\frac{1}{2}} dt. \quad \text{.....(iii)}$$

Our problem is to minimise this integral, and hence R, with respect to variation of the functions $x(t)$, $y(t)$ and $z(t)$, subject to the boundary conditions that these functions and their first derivatives shall take prescribed values at $t = 0$ and $t = T$. In this way we shall minimise R and hence the fuel consumption, for a journey from a given point A (x_o, y_o, z_o), to another given point B (x_1, y_1, z_1) of the field, the velocity at A being specified as (u_o, v_o, w_o), and the velocity at B being given as (u_1, v_1, w_1). The time of transit T will also be regarded as fixed initially, though later we shall minimise with respect to this time also.

The actual process of minimisation is a problem in the calculus of variations and details of the procedure may be found in works devoted to this subject (*e.g.* (2)). The integral is minimised if the following equations in x, y, z are satisfied,

$$\frac{d^2}{dt^2}\left[\frac{\ddot{x} + \partial V/\partial x}{\{\Sigma(\ddot{x} + \partial V/\partial x)^2\}^{\frac{1}{2}}}\right] + \frac{\left(\ddot{x} + \frac{\partial V}{\partial x}\right)\frac{\partial^2 V}{\partial x^2} + \left(\ddot{y} + \frac{\partial V}{\partial y}\right)\frac{\partial^2 V}{\partial x \partial y} + \left(\ddot{z} + \frac{\partial V}{\partial z}\right)\frac{\partial^2 V}{\partial x \partial z}}{\{\Sigma(\ddot{x} + \partial v/\partial x)^2\}^{\frac{1}{2}}} = 0 \quad \text{.....(iv)}$$

etc., etc., there being two similar equations for y and z.

Reference to (ii) shows that these equations may be written more briefly

$$\left.\begin{aligned} \ddot{l} + l\frac{\partial^2 V}{\partial x^2} + m\frac{\partial^2 V}{\partial x \partial y} + n\frac{\partial^2 V}{\partial x \partial z} &= 0 \\ \ddot{m} + l\frac{\partial^2 V}{\partial x \partial y} + m\frac{\partial^2 y}{\partial y^2} + n\frac{\partial^2 y}{\partial y \partial z} &= 0 \\ \ddot{n} + l\frac{\partial^2 V}{\partial x \partial z} + m\frac{\partial^2 V}{\partial y \partial z} + n\frac{\partial^2 V}{\partial z^2} &= 0 \end{aligned}\right\} \quad \text{.....(v)}$$

$V(x, y, z)$ is a given function of position, so that (iv) is a set of simultaneous equations of the fourth order in each of the dependent variables x, y and z. We

expect twelve arbitrary constants to occur in the solution of these equations, and since this is exactly equal to the number of boundary conditions, our problem should possess a unique solution.

Two particular cases are of the greatest interest, *viz.* (*a*) when the gravitational field is uniform, and (*b*) when the gravitational field is that due to an attracting body such as the Earth, Moon or Sun. In the latter case we may take

$$V = -\frac{\mu}{(x^2 + y^2 + z^2)^{\frac{1}{2}}}$$

assuming the origin to be the centre of force. Substitution in (iv) provides us with equations determining the optimum trajectory in this case, but a cursory examination suggests that their solution cannot be obtained by exact methods, so that recourse must be had to approximate numerical methods of integration. The problem is one which is highly suited to a modern electronic calculating engine.

In the former case (*a*), (v) reduces to

$$\ddot{l} = \ddot{m} = \ddot{n} = 0$$

so that l, m, n may be taken as dependent variables, and since there is the identical relationship $l^2 + m^2 + n^2 = 1$ between these quantities, so that there are four equations in three unknowns, we cannot expect there to be a solution in this case. In fact, we find that there is indeed a solution

$$l = l_o,\ m = m_o,\ n = n_o$$

l_o, m_o, n_o being constants such that

$$l_o^2 + m_o^2 + n_o^2 = 1$$

but there being only two arbitrary constants now available, it is easy to show that in the general case the boundary conditions cannot all be satisfied. This method does not lead to an optimum trajectory in this special case, therefore.

There is, however, an alternative approach to the problem which leads to a solution as follows. Writing

$$\frac{\partial V}{\partial x} = f,\ \frac{\partial V}{\partial y} = g,\ \frac{\partial V}{\partial z} = h$$

so that the uniform field has components $(-f, -g, -h)$, and putting

$$p = \dot{x} + ft,\ q = \dot{y} + gt,\ r = \dot{z} + ht \quad \text{.....(vi)}$$

we have to minimise

$$I = \int_o^T (\dot{p}^2 + \dot{q}^2 + \dot{r}^2)^{\frac{1}{2}}\, dt \quad \text{.....(vii)}$$

under the boundary conditions

$$p = u_o,\ q = v_o,\ r = w_o, \text{ at } t = 0,$$

$$p = u_1 + fT = u_1',\ q = v_1 + gT = v_1',\ r = w_1 + hT = w_1', \text{ at } t = T,$$

$$\int_o^T p\,dt = x_1 - x_o + \tfrac{1}{2} fT^2 = \alpha, \qquad \int_o^T q\,dt = y_1 - y_o + \tfrac{1}{2} gT^2 = \beta,$$

$$\int_o^T r\,dt = z_1 - z_o + \tfrac{1}{2} hT^2 = \gamma \quad \text{.....(viii)}$$

Regarding (p, q, r) as cartesian co-ordinates of a point with respect to axes Op, Oq, Or, we first observe that the functions $p = p(t)$, $q = q(t)$, $r = r(t)$ define a twisted curve in this space joining the points (u_o, v_o, w_o) and (u_1', v_1', w_1') and that I is the length of this curve. Secondly, we have by a change of variable of integration to s, the arc length parameter measured along this curve,

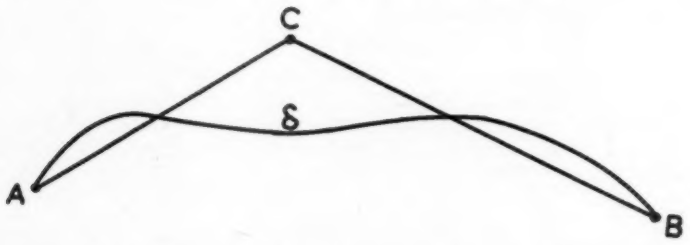
$$\int_o^{\mathrm{I}} p \frac{dt}{ds}\, ds = \alpha, \qquad \int_o^{\mathrm{I}} q \frac{dt}{ds}\, ds = \beta, \qquad \int_o^{\mathrm{I}} r \frac{dt}{ds}\, ds = \gamma \quad \ldots\ldots\ldots\ldots \text{(ix)}$$

This condition may be given a physical interpretation in the following way. Imagine that matter is distributed along the curve so that its line density at the point s is dt/ds. Then the sum total of this matter is

$$\int_o^{\mathrm{I}} \frac{dt}{ds}\, ds = \int_o^{\mathrm{T}} dt = \mathrm{T}$$

and the conditions (ix) are equivalent to stating that the centre of mass of this matter must lie at the point $(\alpha/\mathrm{T}, \beta/\mathrm{T}, \gamma/\mathrm{T})$.

We have shown therefore that our problem is equivalent to that of finding a distribution of matter of mass T, along some curve joining two given points, so that the centre of mass shall lie at a third given point and the length of the curve shall be the minimum possible. Now the solution of this problem is obvious from physical considerations, for if A, B be the two given terminal points and C be the centre of mass, no curve δ, of length less than (AC + CB),



can possibly be the basis of a distribution of matter having C as centre of mass (it being noted that $dt/ds > 0$, so that matter of negative mass cannot be introduced). On the other hand, an infinitely tenuous distribution along AC and BC and a particle of mass T at C satisfies all the conditions. ACB is therefore the minimum curve.

It remains to translate the above result back into terms of the original problem. The passage from A to C occurs theoretically in zero time, since no matter is stationed along this line. It follows that there are initial discontinuities in p, q, r of amounts

$$\alpha/\mathrm{T} - u_o, \quad \beta/\mathrm{T} - v_o, \quad \gamma/\mathrm{T} - w_o,$$

respectively and hence $\dot{x}$, $\dot{y}$, $\dot{z}$ are subject to the same discontinuities. The rocket is therefore subjected to an initial impulse by rapid combustion of fuel, so that its resolutes of velocity are increased by the above quantities. The particle of

mass T at C implies that (p, q, r) are constant for a period T at values $(\alpha/T, \beta/T, \gamma/T)$. Using (vi) we obtain during this period

$$\dot{x} = \frac{\alpha}{T} - ft,$$

$$\dot{y} = \frac{\beta}{T} - gt,$$

$$\dot{z} = \frac{\gamma}{T} - ht,$$

showing that the rocket is falling freely under gravity until $t = T$, at which time it may be verified that $(x, y, z) = (x_1, y_1, z_1)$. The rocket has now arrived at its destination and the passage from C to B corresponds to the terminal impulse which must be applied to bring the velocity into accord with that stipulated in the boundary conditions.

For this optimum programme we have

$$U \log R = I = AC + CB,$$

$$= \sqrt{\Sigma\left(u_o - \tfrac{1}{2} fT - \frac{x_1 - x_o}{T}\right)^2} + \sqrt{\Sigma\left(u_1 + \tfrac{1}{2} fT - \frac{x_1 - x_o}{T}\right)^2} \quad \ldots\ldots \text{(x)}$$

and we can now minimise with respect to time of transit T, by a single differentiation, or, in a particular case, more simply by plotting U log R against T. Such a minimum obviously exists for some finite T, since U log $R \to \infty$ as $T \to 0$ or to ∞.

The reason for the failure of our first method is now clear. The optimum solution requires that the acceleration shall be infinite at both ends of the trajectory and that there shall be no thrust at intermediate points. A method involving the taking of derivatives will invariably fail if the functions involved are discontinuous or possess infinities. Further, l, m, n are indeterminate under conditions of no thrust.

If the rocket is moving in free space away from gravitating bodies we can put $f = g = h = 0$ and the problem is solved.

Referring again to the system (v), we find that there is a further case when these equations are incompatible. This is when V is given by

$$V = ax^2 + by^2 + cz^2 + 2fyz + 2gzx + 2hxy + 2\alpha x + 2\beta Y + 2\gamma z + V_o,$$

where $a, b, c, f, g, h, \alpha, \beta, \gamma, V_o$ are all constant. Generally we can rotate our axes and displace our origin so that the formula for V becomes simply

$$V = ax^2 + by^2 + cz^2 + V_o$$

a, b, c, V_o being new constants. In this case equations (v) may be written

$$\ddot{l} + 2al = \ddot{m} + 2bm = \ddot{n} + 2cn = 0,$$

and it is easily verified that there is no solution satisfying the identity $l^2 + m^2 + n^2 = 1$. Again, therefore, this method leads to no solution. We shall not investigate the matter further, however, since, although the above formula for V may give a good approximation to a practical field over a small

region it cannot represent an actual field over any extensive region, since such a potential tends to infinity as we recede from the origin.

3. The Case of no Gravitational Field

We shall now discuss the programming of fuel consumption and jet direction in the absence of a gravitational field, from a different standpoint to that adopted in Section 2. We shall suppose that the trajectory joining the points A and B has been specified and that it is required to navigate the rocket along this trajectory subject to the condition of minimum fuel consumption. The time of transit is supposed not given, but the velocities v_0 and v_1 at the end points are specified.

Resolving (i) along the tangent and principal normal to the trajectory we obtain

$$v\frac{dv}{ds} = -\frac{\mathrm{U}\cos.\,\alpha}{\mathrm{M}}\frac{d\mathrm{M}}{dt}$$

$$\mathrm{K}v^2 = -\frac{\mathrm{U}\sin.\,\alpha}{\mathrm{M}}\frac{d\mathrm{M}}{dt} \qquad \text{.....(xi)}$$

for there is no resolute of acceleration in the direction of the binormal, so that the thrust, and hence the vector **U**, must lie in the osculating plane.

Eliminating α, we get

$$\left(\frac{\mathrm{U}}{\mathrm{M}}\frac{d\mathrm{M}}{dt}\right)^2 = v^2\left\{\mathrm{K}^2v^2 + \left(\frac{dv}{ds}\right)^2\right\}$$

and, since $v = ds/dt$, we have by integration with respect to t, after the extracting of a square root,

$$\mathrm{U}\log.\,\mathrm{R} = \int_0^{\mathrm{S}}\left\{\mathrm{K}^2v^2 + \left(\frac{dv}{ds}\right)^2\right\}^{\frac{1}{2}}ds. \qquad \text{.....(xii)}$$

$\mathrm{K} = \mathrm{K}(s)$ is supposed given, so that we shall minimise this integral with respect to variation of the function $v = v(s)$. The usual process of minimisation leads to the equation

$$\frac{d}{ds}\left\{\frac{v'}{(\mathrm{K}^2v^2 + v'^2)^{\frac{1}{2}}}\right\} = \frac{\mathrm{K}^2v}{(\mathrm{K}^2v^2 + v'^2)^{\frac{1}{2}}}$$

where dashes denote differentiation with respect to s. This equation reduces to

$$\mathrm{K}vv'' - \mathrm{K}^3v^2 - 2\mathrm{K}v'^2 - \mathrm{K}'vv' = 0 \qquad \text{.....(xiii)}$$

and this is seen to be equivalent to

$$\lambda' = \mathrm{K}(1 + \lambda^2) \qquad \text{.....(xiv)}$$

where $\lambda = v'/\mathrm{K}v$.

Solving (xiv) we find that

$$\lambda = \tan.\,(\psi + \mathrm{A}), \qquad \text{.....(xv)}$$

where

$$\psi(s) = \int_0^{\mathrm{S}}\mathrm{K}\,ds \qquad \text{.....(xvi)}$$

and A is the constant of integration.

It now follows that

$$\frac{v'}{v} = \mathrm{K} \tan. (\psi + \mathrm{A})$$

and hence integrating

$$\log. v = \int \mathrm{K} \tan. (\psi + \mathrm{A})\, ds,$$

$$= \log. \sec. (\psi + \mathrm{A}) + \text{constant}.$$

Whence $$v = \mathrm{B} \sec. (\psi + \mathrm{A}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\text{xvii})$$

where B is a further constant of integration, to be determined, together with A, from the boundary conditions.

From (xi), by division, we find that

$$\lambda = \frac{v'}{\mathrm{K}v} = \cot. \alpha$$

which, with (xv), implies that

$$\alpha + \psi = \pi/2 - \mathrm{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\text{xviii})$$

If the trajectory be a plane curve, there is a simple physical interpretation of this last equation, for then ψ, as given by (xvi), is the angle through which the tangent rotates as the arc length variable s increases from 0 to some general value s. It follows that $(\alpha + \psi)$ is the angle made by the direction of thrust, at any moment, with the direction of the tangent at the starting point on the trajectory, and (xviii) asserts that this angle is constant, i.e. the direction of thrust remains steady throughout the motion. In this case, (xvii) is simply the statement that the resolute of velocity in the direction perpendicular to that of the thrust, is constant, as we should expect.

Returning to the general three-dimensional case, we have the boundary conditions

$$v = v_o \text{ when } \psi = 0$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\text{xix})$$

$$v = v_1 \text{ when } \psi = \psi_1$$

which, upon substitution in (xvii), provide us with equations for A and B, *viz.*,

$$v_o \cos. \mathrm{A} = \mathrm{B}, \; v_1 \cos. (\mathrm{A} + \psi_1) = \mathrm{B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\text{xx})$$

so that

$$\tan. \mathrm{A} = \cot. \psi_1 - \frac{v_o}{v_1} \operatorname{cosec}. \psi_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\text{xxi})$$

$$\mathrm{B} = v_o v_1 \sin. \psi_1 \, (v_o^2 + v_1^2 - 2 v_o v_1 \cos. \psi_1)^{-\frac{1}{2}}$$

Returning to the equations (xi), we find from the second that

$$-\frac{\mathrm{U}}{\mathrm{M}} \frac{d\mathrm{M}}{d\psi} = v \operatorname{cosec}. \alpha$$

$$= \mathrm{B} \sec.^2 (\psi + \mathrm{A})$$

so that upon integration we calculate that

$$\mathrm{U} \log. \frac{\mathrm{M}_o}{\mathrm{M}} = \mathrm{B} \tan. (\psi + \mathrm{A}) - \mathrm{B} \tan. \mathrm{A}$$

$$\text{or } \frac{M_o}{M} = \exp.\left\{\frac{v_o}{U}\sin.\psi \sec.(\psi + A)\right\} \quad \ldots\ldots\ldots\ldots (xxii)$$

where we have made use of the relationships (xx). This equation governs the fuel combustion programme, for we may calculate ψ in terms of t from (xvii), thus,

$$v = \frac{ds}{dt} = B \sec.(\psi + A)$$

Therefore

$$t = \frac{1}{B}\int_o^s \cos.(\psi + A)\, ds$$

$$= \frac{1}{B}\int_o^{\psi} \cos.(\psi + A)\frac{d\psi}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots (xxiii)$$

and K can be expressed as a function of ψ.

(xviii) governs the thrust direction programme.

Putting $\psi = \psi_1$ in (xxii), we obtain

$$R = \exp.\left\{\frac{1}{U}(v_o^2 + v_1^2 - 2v_o v_1 \cos.\psi_1)^{\frac{1}{2}}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (xxiv)$$

where we have made use of (xx) and (xxi).

In the case of a two-dimensional trajectory, ψ_1 is the total angle of rotation of the tangent and is independent of the trajectory, being equal to the angle between the tangents at the end points. In this case therefore, the optimum mode of transit along any trajectory connecting the end points and having tangents at these end points in the specified directions of the velocities there, results in the same fuel consumption. Inspection of (xxiv) reveals that the fuel consumption is precisely that necessary to convert the vector velocity v_o into the vector velocity v_1. This is an obvious minimum requirement upon the fuel, so that the value of R we have obtained is certainly a minimum and our analysis merely shows that there are any number of modes of transit between the two end points, for which the fuel consumption is the minimum possible.

In the case of a twisted trajectory, ψ_1 depends on the curve selected and we therefore seek a curve which minimises ψ_1 and hence R. It appears from the reasoning of Section 2, that the best possible mode of transit is that described in that section minimised with respect to a variation of T. This mode takes the form of two impulses applied at the ends of the trajectory, the motion between these impulses being that of uniform velocity along a straight line. The trajectory minimising ψ_1 may therefore be described as follows. At either end the tangent is subject to a sudden rotation from the specified directions into line with that of the straight line joining these end points and otherwise the curve is straight. It may now be verified that (xxiv) gives the same value for R in the case of this trajectory, as may be obtained from the Section 2 formula by minimisation with respect to T.

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THE RESEARCH SCENE—5

By Kenneth W. Gatland

New Propellants Tested

A report from the N.A.C.A. Flight Propulsion Laboratory, Lewis, states that two new high-performance rocket propellants have recently been tested:—(1) diborane*/oxygen, and (2) hydrogen/fluorine. No other particulars are available.

The Boeing BEMAC Computor

An automatic computor, which simulates the flight of guided-missiles, has been designed and built by the Boeing Aircraft Company's Engineering Division Physical Research Unit. The BEMAC (Boeing Electro-Mechanical Analogue Computor) simulates mathematically every characteristic of a missile through the use of analogous voltages and mechanical shaft positions; the sum of these—in a mathematical sense—representing the missile. Into this set of characteristics are fed known quantities, such as strength and direction of the propulsive force and various atmospheric data. In operation, the flight path of the missile is represented by a moving series of dots.

The computor can be utilised in sections to work two or more relatively simple problems simultaneously. It is, in fact, possible to integrate up to 20 variables, 10 two-variable problems, 5 four-variable problems, or one 20-variable problem.

The BEMAC was designed primarily for use in the development of the GAPA ground-to-air rocket, and although the device can never completely replace field experimentation, it should materially reduce the number of free-flight tests required for any one project.

Development work on the GAPA missile, now entering its fifth year, is still proceeding at the Boeing factory at Seattle; test firing is carried out at Alamogordo, New Mexico.

Operation "G"

Tests have recently been made by the United States Air Force at Muroc Dry Lake, California, to discover human resistance to rapid deceleration.

A rocket-propelled sleigh, running on sliding shoes over 2,000 ft. (610 m.) of railed track, was used in the experiment; the volunteer faced rearwards in an ordinary aircraft seat and was secured with a special harness. On entering the 45-ft. (13·7 m.) braking section of the vehicle was capable of slowing from 150 to 75 m.p.h. (241 to 120 km./sec.) in one-fifth of a sec., and the occupant safely withstood deceleration forces of 35 g.

Experiments with rocket-propelled sleds were originally made at Muroc during 1946–47, when they were considered as an alternative to the supersonic wind tunnel; velocities exceeding 1,000 m.p.h. were achieved on several occasions.

The technique of rocket-rail sleds has been developed by Northrop Aircraft, Incorporated, Hawthorne, California.

* B_4H_{10}, a boron hydride, also known as borobutane.

The Fairchild "Lark"

The Fairchild *Lark* (XSAM-N-2) has recently completed a series of flight tests for approval by the United States Navy. It is seen in the accompanying photograph rising under the assistance of the two boost rockets.

The LARK, a surface-to-air guided missile, shown during launching at the Naval Air Missile Test Centre, Point Mugu, California, where developmental testing is being conducted. Powered by a liquid rocket engine, the Lark is being developed by the Fairchild Engine and Airplane Corporation and Consolidated Vultee under contract with the Bureau of Aeronautics. Smoke trails visible in the picture are from booster rockets used to accelerate the missile up to its flying speed.

The Douglas Automatic Analyzer

A considerable advance has recently taken place in the development of recording and computing mechanism for rocket tests.

The Douglas Aircraft Co. have produced for U.S. Army Ordnance an automatic analyser, reputed to reduce by 80 per cent. the time and cost of interpreting data telemetered from rockets. The machine was designed to interpret data produced by a pulse-time telemeter system which transmits readings from 28 instruments in the missile during flight. The signals are recorded by ground stations on continuously moving 35 mm. film in groups of 28 straight, parallel lines measuring 0·004 in. (0·102 mm.) in breadth. Quantities being measured are registered by varying lengths of these fine lines; since some 900 lines are recorded on about 12 in. (0·305 m.) of film per sec. of flight, there may be as many as 150,000 readings to be checked and analysed in a single test.

In giving this information, B. S. Benson, a Douglas research engineer, said that the task of analysing data telemetered from missiles to ground stations had always presented a formidable problem. Before the data recorded can be made available for use, it has to be unscrambled, calibrated and plotted to suitable scales. Benson pointed out that human beings are not well suited to such meticulous and tedious tasks and that it is difficult to find personnel who can apply themselves to this work for long periods. The machine, on the other hand, will work relentlessly day or night at this specialised task. It not only counts the lines, selecting some for measurement, and passing others, according to its instructions, but also makes corrections for what would otherwise be misleading errors in the record, such as missing or spurious lines. It watches for fluctuations in certain calibration channels, and signals if adjustments are necessary. The information is delivered in final plotted form ready for inclusion in reports and use by the research personnel.

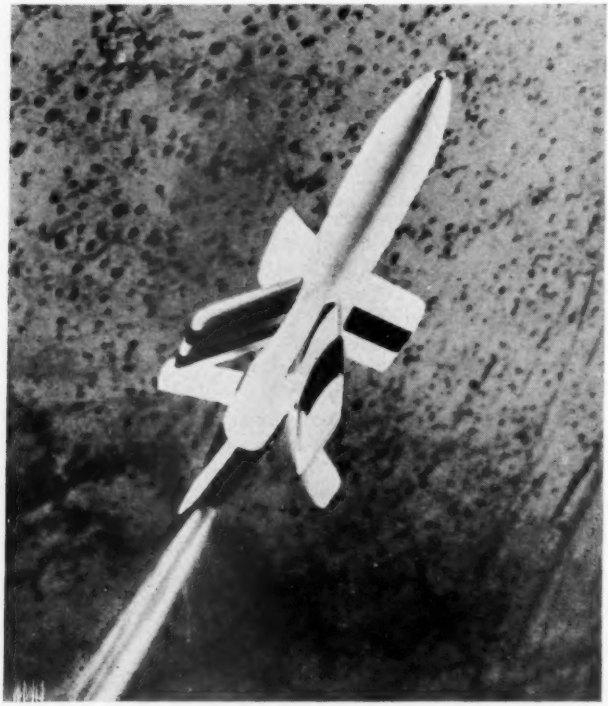
The Douglas analyser is claimed to perform more rapidly, more accurately and more consistently than its human counterpart, and to have already saved thousands of dollars and many months of time for missile research teams. The time element is often extremely important, because where the volume of work is large, one may be faced with the choice of delaying a firing programme or of sending a missile aloft without sufficient benefit being made of information obtained from a previous firing.

The Ryan "Firebird"

An air-to-air missile, known as the *Firebird*, has been developed by the Ryan Aeronautical Co. Originally intended to go into production for the United States Air Force, the project was later relegated to an experimental status and will now become the research basis for future guided weapons.

The present missile is 7·5 ft. (2·3 m.) in length with a maximum diameter of approximately 6 in. (150 mm.): sustaining power is supplied by a bi-fuel rocket unit in the main housing, after initial assistance from a fin-less rocket booster (2·5 ft.—0·76 m. long) forming a streamlined tail. The booster is jettisoned by an explosive charge.

Flight tests have been carried out in conjunction with the twin-fuselage *Mustang* at Holloman Air Force Base, Alamogordo, New Mexico. The rocket embodies aerodynamic surfaces and a compact radar navigational system and is designed to "home" on its objective; it is claimed to be capable of violent manœuvres in order to follow the target. The wings and tail vanes are arranged in a double-cruciform, the four wings (span, 3ft. — ·914m.) being located about mid-way along the main body approximately 2 ft. (0·61 m.) ahead of the vertical and horizontal tail surfaces.



The "Firebird" air-to-air missile.

The *Firebird* can be launched singly or in multiples from external racks and is initially aimed by radar. A proximity fuse is fitted and the missile's destruction in the event of a miss is assured by a safety exploder.

In the interests of economy, initial flight tests have not included the guidance mechanism, which separately has been subject to extensive ground testing.

The *Firebird*, designated XAAM-A-1, is the product of a two-year experimental programme, costing $2,000,000.

NOTES AND NEWS

International Conference on Astronautics

Further details of the first Astronautical Congress in Paris are now available. Organised by M. Ananoff of the *Groupement Astronautique Français*, and attended by representatives of most of the European societies, it will be held from 30th September to 2nd October inclusive. The first meeting, on 30th September, in the Sorbonne, will be open to the public. Subsequent meetings will be between the official delegates of the various societies, and plans for improved co-operation between these bodies and for the projected London Conference in 1951, will be discussed. Further information can be obtained from the B.I.S. Secretary, and anyone wishing to attend the 30th September meeting, or having any suggestions for points to be raised, is invited to write to him. It is expected that several members of the B.I.S. Council will attend on behalf of this Society.

Nominations for Council, 1950/51

In accordance with the provisions of Article 15 of the Society's Constitution, one-third (i.e. *four*) members of the Council will retire from office at the fifth Annual General Meeting, which will be held on Friday, 8th December, 1950, at 6.15 p.m.

Nominations are invited from members for election to the Council for next session. Under the provisions of Article 13, it will be possible to elect two Members to the Council on this occasion, as one Member, Mr. Gillings, is already serving.

Signed nominations should be forwarded to the Secretary as soon as possible, and in any event, not later than 27th October, 1950. Voting papers will be prepared and forwarded to all members for completion and return before the date of the meeting.

Lending Library

Enclosed with the May *Journal* was a leaflet giving details of a number of books which are now available on loan to Fellows of the Society resident in Great Britain.

Due to the amount of time involved in running even a limited scheme, it has been decided to restrict the lending library to *Fellows only*, for an initial period, and to review, in the light of later experience, the question of making the lending arrangements generally available, by which time it is hoped it may prove possible also to extend the list of books.

The present titles include a few of the classic works and nearly all of the modern books on rocketry and space travel, together with a few on astronomy and other associated sciences, which are not easily obtainable.

In addition to the above books, the Society also conducts a loan scheme whereby copies of articles and reports are made available to both Members and Fellows resident in Great Britain and for which tickets are not required. This scheme numbers some 300 reports at present, but is being extended continually, and most of the items mentioned in the Abstracts section of the *Journal* are added.

New members might also be particularly interested to learn that the article loan scheme also maintains copies of most foreign society journals, e.g. *Pacific Rockets, Journal of the American Rocket Society, Weltraumfahrt,* and many others, as well as a file of past B.I.S. publications.

Library tickets should be obtained in the first instance from the Secretary and are renewable annually, but all applications for books, articles, etc., should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks., who is always willing to assist members who desire particular sources of reference, if these are not immediately available at the current time.

BBC Television talks

Many members will no doubt have seen the two television talks recently given by Arthur C. Clarke; we understand that others are likely to follow.

Of the two already delivered, the first (on May 4) was entitled "The Fourth Dimension," and consisted of an entertaining dissertation on the properties of Flatland, with the usual analogies being drawn as to how four-dimensional space would seem to us, as dwellers in an apparently three-dimensional Universe. The relevance of these matters to Einstein's "finite but unbounded" conception of curved space was pointed out.

The second talk (on May 23) was on a subject more usually associated with the speaker; commencing with an impressive sequence of film taken from an A.4(V.2) rocket ascending to a height of 100 miles over New Mexico, it went on to show a considerable number of the wonderful Bonestell illustrations from the book *Conquest of Space.* These were presented in a most effective manner, with the television camera tracking up to and across the pictures in a way which heightened the sense of realism. Those familiar with Bonestell's work in the original, however, cannot have failed to feel that it lost much of its magic on the black-and-white of the television screen, with its attendant distortions. Throughout this second talk, Clarke did not appear, but his familiar voice was to be heard delivering an excellent commentary in suitably hushed and reverent tones.

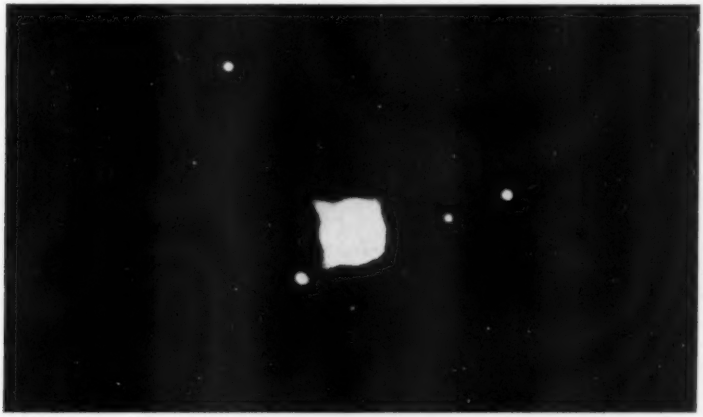
In the first talk we had the speaker in full view most of the time, and it would appear that the B.I.S. now has at least one first-rate television personality.

The New Satellites—Miranda and Nereid

We are reproducing on the opposite page two photographs taken by Dr. Kuiper with the 82-inch reflector at McDonald Observatory showing the recently discovered fifth satellite of Uranus, now named Miranda, and the second satellite of Neptune, for which the name Nereid has been chosen.

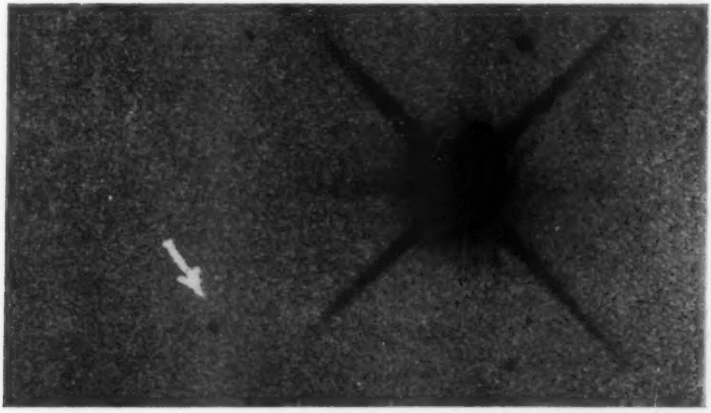
Nereid was found on plates exposed for 40 minutes, on May 1, 1950, when it appeared as an object of magnitude 19·5. Subsequent observations show that it has a period of about two years, and that the plane of its orbit is within five or six degree of the ecliptic.

Dr. Kuiper says that, as Neptune could retain satellites nearly ten times as far away as Nereid, i.e. with periods of up to about 50 years, further work is planned to cover the outer regions of the system (*B.A.A. Circular,* No. 312, 1949).



Uranus and its five satellites.

The recently discovered satellite, Miranda, is the minute object within the halation ring. Its apparent magnitude is 17, its period is about 34 hours, and its mean distance from Uranus about 81,000 miles. Discovery of this moon was made by Dr. Kuiper on February 16, 1948, with the 82-inch McDonald reflector.



Neptune and its two satellites.

Triton is shown close to the planet, while therecently discovered second satellite, Nereid, is indicated by the arrow. Note that, unlike the photograph above, this is a reproduction of the original negative.

Conversazione Photographs

A number of photographs taken at the Conversazione on October 1, 1949, were exhibited at the General Meeting held in November.

Copies of many of these prints, size 8 in. × 6 in., at 3s. 6d., and 6 in. × 4 in. at 2s., post free, are obtainable by members.

Those available are as follows:—

2099–1	K. W. Gatland, explaining his Expendable-Tank Step-Rocket exhibit to visitor.
2099–2	L. J. Carter, A. C. Clarke, and A. V. Cleaver, in a discussion.
2099–3	R. A. Smith, and nine-year-old John Dawson.
2099–4	S. Lane and Miss Linch, examining an artist's representation of a rocket being launched on its return journey from the Moon.
2099–5	K. L. Pascoe examining a globe of Mars.
2099–7	B. R. A. Shaw and Miss Hunter looking at a spaceship drawing.
2099–9	K. S. Bleach looking at some of the rocket-stamp exhibits.
2099–10	J. H. Lowden discussing rocket construction with P. W. C. Monk.
2099–11	Mrs. Lowden looking at rocket technical literature on display.

Orders and remittances should be addressed to Pictorial Press, Salisbury Square, Fleet Street, E.C.4.

From the World's Press

As a footnote to the February 4 discussion (reported in the May, 1950, *Journal*) on world population trends, some observations of Prof. Kirtley F. Mather in a recent UNESCO pamphlet are of great interest. He points out that the widespread application of science has two effects. Firstly, there is the obvious one of increasing expectation of life, due to better medical facilities, social hygiene, etc.; this increases population. Secondly, with the resulting industrialization and increase in living standards, comes a decrease in birth rates; this opposes the first trend and restores a state of equilibrium.

So far, the first effect has been noticeable all over the world, while the second has influenced only the white race to any marked extent. World population therefore appears to be increasing alarmingly, with the proportion of coloured to white races also rising. (Some years ago, the reverse was true; only the white race was then subject to the first effect.) However, Prof. Mather believes that within the next few centuries, the second effect will begin to make itself felt on the coloured people also, so that the total world population will eventually stabilise at "certainly not more than 4,000 million" by about 2050 A.D.

He adds "That is not too many people for the Earth to support," on the assumption that more scientific methods of food production will continue to be applied.

* * * *

In a lecture to the British Astronomical Association on March 19 (which was widely reported in the Press), Dr. J. G. Porter (the President of the Association) said that he regarded the eventual development of spaceships as "inevitable."

* * * *

Apparently as some sort of special display to catch the public eye, the Hayden Planetarium at the American Museum of Natural History in New York opened a "travel bureau," at which visitors could make reservations for interplanetary flights, starting from the "Central Park Spaceport" in 1975. It would seem that some newspapers took this rather more literally than can have been intended; we liked particularly the report of Lloyd's being approached for an £18,000 policy to cover a trip to Mars! However, perhaps it was a better risk than a Liberal candidate's deposit.

* * * *

The book *Modern Arms and Free Men*, by Dr. Vannevar Bush, has attracted a great amount of Press comment in recent months. Dr. Bush, as principal adviser to the U.S. government on scientific warfare, of course writes with great authority, and we would be the last to dispute his literal theme, to the effect that the horrors of a highly scientific war in the relatively near future have been greatly exaggerated in certain quarters. However, some of his remarks about the essential limitations of rocket vehicles (and even more so, the way in which these have been put over by the popular press), have a strangely familiar ring. We remember how frequently it was "proved" by experts, in the between-wars years, that aircraft would never have ranges much in excess of 1,000 miles, or speeds greater than about 200 m.p.h., while carrying any worthwhile disposable loads.

* * * *

In its April 17 issue, *Time* dealt with the latest crop of flying saucer stories, propagated by the magazines *True* and *U.S. News*. Much of the blame for this persistent affair was laid by *Time* squarely at the door of a Commander McLaughlin, one-time chief of the U.S.N. guided-missiles unit at White Sands. According to *Time*, while in this post he reported to his Admiral that he had personally sighted a sky-born saucer; the Admiral replied with a question: "What kind of whisky are you drinking out there?" and transferred McLaughlin to command of a destroyer at sea. (We wonder whether this was altogether wise; if the worthy Admiral's suspicions were justified, at the very least he was letting himself in for a whole series of sea-serpent stories.)

In the meantime, we note that the Texas State Fair has offered a reward of £18,000 for a genuine flying saucer of interplanetary origin—also (from *Aero Digest*) that an American aeronautical scientist has felt moved to build and fly a model "saucer" of semi-helicopter type.

* * * *

During the last few days of 1949 all newspapers carried the story of a new extension to his famous and epoch-making theory of relativity by Albert Einstein, attempting to correlate the phenomena of gravitational and electromagnetic fields. The world of theoretical physics seemed disinclined to offer any immediate comments, but promptly set-to in an effort to digest the new offering. There is apparently some difficulty in devising an adequate experimental check on the new theory, and Einstein himself is reported to have said that he thought many years might elapse before it was verified or otherwise.

Certainly there will be a lot more to it than might be thought from the brevity of the four tensor equations printed rather ingenuously by many papers, as constituting the "Key to the Universe"!

* * * * *

If Einstein's new theory finally throws sufficient light on the nature of gravity to enable us to control this enigmatic and fundamental force of Nature, the news will presumably be welcomed by all science-fictional inventors of "space-warps," and by those astronautically-minded rocket engineers who occasionally harbour secret heretical doubts regarding the complete suitability of their brain-children for interplanetary propulsion. Also likely to hail the news with joy will be Roger Babson, of New Boston, U.S.A.

Paraphrasing the story about Mark Twain and the weather, *Time* for January 2, reports that Mr. Babson (a 74 year-old economist) is worried because lots of people talk about gravity but no one does anything about it. He has therefore started a "Gravity Research Foundation," and has just awarded 1,750 dollars in prizes in an "anti-gravity" essay contest. Unfortunately, none of the 88 papers entered in the competition provided the vital answer, which may nevertheless one day emerge from the continuing advance of modern physics.

* * * *

In the light of the preceding items, the following extract, from the recent Presidential address to the Newcomen Society for the Study of the History of Engineering and Technology, is interesting. Speaking on "Some Reminiscences of Early Aviation," Dr. A. P. Thurston, M.B.E., M.I.Mech.E., said:—

> "Great as the advance has been in the past 50 years, there is every possibility of much greater advance in the next half century. We know that gravity is merely an acceleration. It is clear that, with increased knowledge of the internal construction of the atom, ways will be found to counteract this acceleration by means other than the momentum of air. All this advance has been achieved by the hard and constant thinking of the human brain. Can one doubt that, in the future, all things are possible to the mind, which, like Greek fire, is immortal, and not to be quenched?"

* * * *

The latest development in flying saucers has been a whole crop of rumours in the States claiming them as spaceships from another planet (Venus was particularly favoured as home base); these stories have been fairly widely reported in British papers, and were dealt with at some length in *Time* for January 9. Apparently the American magazine *True* (!) started the flood, by saying: "For the past 175 years the planet Earth has been under systematic close-range examination by living, intelligent observers from another planet." This bare proposition was soon improved upon, and accounts were forthcoming of force-landed and wrecked extra-terrestrial spaceships, discovered in New Mexico, with and without their horribly killed or still happily surviving crews. A Washington spokesman found it necessary to state: "Air Force studies of 'flying saucers' lend no support to the view that they may come from another planet," and the "Project Saucer" group at Wright Field, set up to study all

reports on such objects, was disbanded. It was thought that its continued existence encouraged the rumours, by suggesting that there might be something in them.

All this seems to us to prove the enormous influence which science-fiction and the so-called "comic" strips must have exerted in America. We also observed to Arthur Clarke what glorious fun it would be (or would it?) if one day one of these stories turned out to be true, but he replied that, after this, no visiting Venusian would ever be able to convince his discoverers that he was anything but a hoax.

* * * *

The *Manchester Guardian*, in a despatch from Adelaide dated 30 May, said that the Australian Rocket Range project may cost £50 million before it is completed, instead of the originally-estimated £12 million. The more surprising information was also given that the residents of Woomera like living there; they say "The place grows on you!"

* * * *

The May issue of the magazine *Courier* contained an article headed "London's 'other' Society Life." Along with the Associations of United Laundries, British Jumping, and Superphosphate Manufacturers, to say nothing of the National Society of Children's Nurseries ("Away for din-din; back at fwee"), one inevitably finds the B.I.S. However, we are described as "pure and deadly serious scientists": we believe this was meant to be complimentary, and are suitably grateful—though we blush at the sometimes undeserved tribute to our purity, admit to occasional lapses from seriousness, and hasten to refute the nowadays widespread impression that scientists are inevitably deadly.

* * * *

In a "science-fictionalized" review of Arthur Clarke's book "Interplanetary Flight," the *Daily Mirror* gave the astonishing news that British atomic scientists are now waiting for the go-ahead from the Government to build an atomic engine which could be used as a rocket propulsion unit: "The B.I.S. has already drawn up the plans." We do not know how many of our pure-minded (see above) readers also read *The Daily Mirror*, but for the benefit of those who do, we feel we should explain that the report in question is, at least, premature.

* * * *

Our Mr. Clarke also suffered an interview in the Paris edition of the *New York Herald Tribune* recently; describing him as a "British scientist who hopes to rocket around the Moon in about 20 years," this was headlined: "Plans Lunar Trip in 20 years; Says Russians May Beat Him."

* * * *

Every batch of press cuttings we receive these days contains several newspaper accounts of statements by reputable scientific men to the effect that they believe in the possibility of interplanetary flight; clearly our subject is on the verge of becoming completely respectable. (Though not, we hope, dull in consequence.)

In recent months, the list includes physicist Dr. R. E. Gibson, of Johns Hopkins University, and astronomer E. G. Reuning, of the U.S. Naval Observatory—who thought future spaceships would probably be guided from Earth because the complicated calculations of their orbits would require the services of elaborate electronic computors.

The United Nations organization held a radio symposium in New York during April, in connection with the fifth anniversary of the International Civil Aviation Organization. Interviewed on this programme, Igor Sikorsky (famous as a pioneer of large aircraft, flying boats and helicopters) said: "It appears that, within a decade or two, it would be possible to produce a vehicle that would carry a man, with instruments, to the outer border of the Earth's atmosphere or perhaps even beyond it into the mysterious depths of interplanetary space." If it ever proved practicable to use atomic energy in rockets: "interplanetary communication might no longer be impossible."

On the other hand, we have been amused to see that some papers have seized on the remarks of Prof. Picard (the physicist and stratosphere balloonist), in his recent book *Between Earth and Sky*, as implying that spaceflight is impossible, while others have adopted the exactly opposite interpretation. Actually, Picard took the view that a Lunar trip was theoretically possible, but practically improbable, at any rate for a long time to come.

* * * *

The *Egyptian Mail* in a depressing editorial, points out all the "international" complications that would ensue from the achievement of interplanetary flight, culminating in large-scale disputes over Olympic Games with extra-terrestrial competitors. The writer concludes: "It is incumbent upon (the nations of the Earth) to put their own world straight before they can think of flying to the Moon."

* * * *

Speaking at a joint meeting of the A.R.S. and the American Society of Mechanical Engineers held in Washington during April, Mr. H. B. Horne said that the fast-growing U.S. rocket industry may suffer from the very speed of its own development. "It is frequently necessary for contractors to begin the development of a new and more complex engine before its predecessor type has had a chance for field operation at all," declared Horne, who is an executive of Reaction Motors, Inc. To the best of our information and belief, this suggests a very different state of affairs from that applying to British rocketry!

* * * *

Library Acknowledgments

The Council wishes to acknowledge with thanks a copy of *The Planet Mars* by Gerard de Vaucouleurs, kindly donated by Mr. Patrick Moore, who translated the present English edition from the original French.

Further thanks are also due to Mr. T. H. Mountain, who has kindly presented the library with a copy of *Aeronautical Engineering*, edited by R. A. Beaumont.

ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles of journals were given in the May, 1950 issue of the *Journal*. The following is an addendum to that list.

Amer. Aviation	American Aviation.
Appl. Mechs. Revs.	Applied Mechanics Reviews.
Brit. J. Appl. Phys.	British Journal of Applied Physics.
Bull. Soc. Astr. Pop., Toulouse	Bulletin de la Société Astronomique Populaire, Toulouse.
Commun. Pure Appl. Math.	Communications on Pure and Applied Mathematics.
J. Amer. Chem. Soc.	Journal of the American Chemical Society.
J. Chem. Phys.	Journal of Chemical Physics.
J. Roy. Art.	Journal of the Royal Artillery.
J. Southern Res.	Journal of Southern Research.
J. Space Flight	Journal of Space Flight. (Chicago Rocket Society).
Mon. Not. Roy. Astr. Soc.	Monthly Notices of the Royal Astronomical Society.
Pop. Sci. Mon.	Popular Science Monthly.
Prod. Engng.	Product Engineering.
S. Afr. J. Sci.	South African Journal of Science.
Soc. Automot. Engrs. J.	Society of Automotive Engineers Journal.

Many of the Abstracts noted are available on loan to members resident in the British Isles. Requests should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.

The disbandment of the rocket troop in 1816. H. B. LATHAM. *J. Roy. Art.*, **76**, 277-80 (Oct., 1949).

On the kinetic theory of rarefied gases. H. GRAD. *Commun. Pure Appl. Math.*, **2**, 331-407 (Dec., 1949).

Investigation of the excitation of molecular vibrations by high-speed missiles. Z. I. SLAWSKY. *Phys. Rev.*, **76**, 882 (Sept. 15, 1949).

The viscosity and heat conductivity of steam. F. G. KEYES. *J. Amer. Chem. Soc.*, **72**, 433-6 (Jan., 1950) (18 refs.).

The thermodynamics of flow systems. C. F. CURTISS and J. O. HIRSCHFELDER. *J. Chem. Phys.*, **18**, 171-3 (*Feb.*, 1950).
The rate of change of entropy in a flow system is evaluated explicitly taking into account heat conductivity, viscosity, diffusion, and chemical reactions. The equations are developed rigorously from the kinetic theory of gases.

On ionisation and luminescence in flames. E. SÄNGER, I. BREDT and P. GOERCKE. *C. R. Acad. Sci., Paris*, **230**, 949-51 (*March* 6, 1950). *In French.*

The Earth's upper atmosphere. D. R. BATES. *Mon. Not. Roy. Astr. Soc.*, 109, 215-45 (1949). Summary of present knowledge.

Chemical composition of the stratosphere at 70 km. height. K. F. CHACKETT, F. A. PANETH and E. J. WILSON. *Nature*, **164**, 128-9 (*23rd July*, 1949). Analysis of air samples taken during V.2 flights.

What upper air means to missiles. R. MCLARREN. *Aviation Wk.*, **51**, 21-2, 24-5 (*22nd Aug.*, 1949). Abstract of Rand report. (14 refs.)

Rocket to drop sky eye. V. TORREY. *Pop. Sci. Mon.*, **155**, 127-9. (*Dec.*, 1949). Device to measure radiation from sun, earth and sky.

Environmental warmth and human comfort. T. BEDFORD. *Brit. J. Appl. Phys.*, **1**, 33-8 (*Feb.*, 1950).
The measurement of body heat production is discussed, and sample rates of heat production for various forms of activity are quoted. The physiological mechanisms which

regulate the rate of heat loss are described. Various scales of warmth which take into account other environmental factors besides air temperature are described and their validity discussed. The "comfort zone" is defined in terms of these scales of warmth. (18 refs.)

Report on the development of injection nozzles and burner-forms and the design of the associated test-plant. TRAUEN. *U.S. Dept. Comm., Off. Tech. Serv. PB* 97160, 5 p.

Test equipment and several types of burner are described. Investigations on the quantity-distribution in the jet, the droplet size, and the influence of air movement on the mixing are discussed.

High gas discharge velocities in rocket propulsion. E. SÄNGER. *U.S. Dept. Comm., Off. Tech. Serv. PB* 96227, 21 p. (*Nov.*, 1946).

Considers exhaust discharge velocities up to 5,000 m/sec. possible.

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Rocket launcher. C. C. Lauritsen and J. McMorris. *U.S. Pat. No.* 2,458,476. (4*th Jan.*, 1949.)

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Magazine rocket launcher. L. S. MacDonald. *U.S. Pat. No.* 2,468,216. (26*th April*, 1949.)

Means for cooling projected devices. R. H. Goddard. *U.S. Pat. No.* 2,468,820. (3*rd May*, 1949.)

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Rocket-propelled device. M. H. Goehmann. *U.S. Pat. No.* 2,470,162. (17*th May*, 1949.)

Rifle rocket missile. N. M. Hopkins. *U.S. Pat. No.* 2,470,489. (17*th May*, 1949.)

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Three and one-half times the speed of sound. *Antiaircr. J.*, **92**, 14 (*July*, 1949).
Details of Viking design.

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Proving ground for rockets. R. E. STOCKWELL. *Aviation Operations*, **12**, 32, 33, 65-7 (*Aug.*, 1949).

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Projectile operating with rocket propulsion. C. D. BURNEY. *U.S. Pat. No.* 2,489,953. (29*th Nov.*, 1949.)

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Different types of guided missiles are defined. Effectiveness of each type is compared and methods of propulsion discussed. Methods of guidance are also discussed and directions in which further research is needed are pointed out.

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Equations, simplified for approximate application to small angles of yaw (20° or less), are written and solved. The results are plotted in generalized coordinates, and the curves may then be used for the solution of specific cases.

Two aspects of rocket flight. R. H. MACMILLAN. *Aircraft Engng.*, **22**, 46-7 (*Feb.*, 1950). Stabilizing finless rockets by spinning and the potentialities of multi-stage rocket projectiles.

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Astronautics and the German V.2. L. ROY. *Bull. Soc. Astr. Pop. Toulouse* (300), 31-45 (*Feb.*, 1949). (*In French.*)

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Astronautics: a study. M. ANWAR. *Indian Skyways*, **3**, 25-30 (*June*, 1949).

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The design of a practical space-ship. W. PROELL. *J. Space Flight*, 1. Pt. 1, 1-9 (Sept., 1949) Pt. 2, 1-9 (Oct., 1949); Pt. 3, 4-11 (Nov., 1949).

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Rocket primer. L. A. SKINNER. *U.S. Pat. No.* 2,462,135. (*22nd Feb.*, 1949).

Organic solid rocket monopropellants. A. J. ZAEHRINGER. *Rocketscience* (*June*, 1949). The physical and chemical properties of organic monopropellants, mainly nitro compounds, are reviewed.

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Ing. Guido Peter von Pirquet.
Elected Honorary Fellow of the B.I.S. in 1949.

ING. GUIDO von PIRQUET

The youngest of a family of seven, Ing. Guido von Pirquet was born on March 30, 1880, in the castle of Hirschstetten (near Vienna), which was almost completely destroyed by bombing in the Second World War. His father was Baron Peter Pirquet, an Austrian diplomat and landowner, who frequently took one or another of his children along with him on his various trips abroad.

In the peaceful and dignified atmosphere of those far-off pre-1914 days, the young von Pirquet grew up on his father's estate, taking advantage of his many opportunities for pursuing the sports of swimming and horseback-riding and generally leading a healthy open-air life, tempered with an interest in the arts and music. His home background led to his developing a liking for natural history, but his scientific interests soon turned in the direction of mathematics and the physical sciences, with a taste also for practical handicrafts.

He qualified as a mechanical engineer at the Technical High Schools of Vienna and Graz, and in 1903 did his military service with the old Austrian Imperial Navy in the Mediterranean. In 1922, he married Frieda Pramer. He has been Vice-President, and Chairman of the Technical Examinations Committee, of the Austrian Society of Inventors, and has himself taken out various patents in the fields of thermal engineering and agricultural machinery—the latter pre-occupation again following from his early background.

Like so many of those devoted to the early development of astronautics, Guido von Pirquet's life affords abundant evidence of a fertile and active mind engaged in an amazing catholicity of activities. His work has ranged from ballistics to philosophical problems, such as the study of the true nature of invention and the qualities of truth and free will, and the real economic value of goods and inventions. He has always been an enthusiastic advocate of the principle of harnessing ocean wave and solar power, in preference to the prodigal expenditure of the Earth's store of coal and oil fuel, and has made studies in the fields of meteorology and geology, particularly the mechanism of volcanic action.

In the purely astronautical sphere, von Pirquet has written no classic book like others of the great pioneers, but from the nineteen twenties to the present day has been responsible for a stream of articles on the subject, which have been published in many books, magazines and papers. In particular, he made valuable contributions to the Journal of the V.f.R. (*Die Rakete*) and to Werner Brügel's book *Männer der Rakete* (1933). These covered many aspects of space flight, from rocket thermodynamics to the conception of using the space-station as a springboard for true interplanetary voyages.

This latter idea of refuelling the spaceship in a stable orbit near to Earth, before proceeding further with the journey to the Moon or other planet, must be regarded as von Pirquet's great contribution to the subject. Other writers also dealt with the scheme, but Guido von Pirquet pioneered the idea and developed it most fully, demonstrating the immense savings in vehicle size (and initial thrust) which it theoretically made possible. Readers of this *Journal* know that, in the view of the B.I.S., the employment of these powerful

techniques of orbital refuelling places the whole interplanetary project in an altogether more favourable light. It is hardly too much to say that, in the easily-foreseeable future, only such techniques can show any reasonable prospects of making return voyages to the planets practicable. Von Pirquet himself has expressed this in what he calls "The Cosmonautical Paradoxon": once the space station is established, all the most difficult of interplanetary problems are, in effect, solved.

REVIEWS

Kleine Raketenkunde

(Hans K. Kaiser. Pp. 151, 90 figs., DM 9. Mundus-Verlag, Stuttgart.)

This well-produced and lavishly illustrated book is concerned primarily with rockets rather than space-flight. It contains a large number of photographs, many of which have not been seen before in this country, and gives much new information about German research before and during the war.

Opening with a short history of the rocket from the earliest times, the book gives a simple account of rocket theory and goes on to discuss the work of the leading authorities—devoting, incidentally, almost equal space to Goddard and to Oberth. Photographs of all the most prominent workers and accounts of their experiments are given, and there is an amusing account of some of the more eccentric personalities who were attracted to the idea of astronautics in its early days. One would like to have known more about the great battle between Oberth and von Hoefft in 1929 ("Nach dieser Zeit hat man in Deutschland nichts mehr von Hoefft gehört . . ."), but Herr Kaiser dismisses von Ulinski's "cathode spaceship" a little too hastily. No doubt von Ulinski's conception was unworkable as it stood, but the fundamental idea is sound for the special applications discussed by Shepherd and Cleaver in their study of the "ion rocket." (*J.B.I.S.*, March, 1949.)

In the account of modern developments, perhaps the most interesting section is that devoted to Peenemunde, and in particular to the firing of the first V.2's. One can well imagine the suspense when No. 1 disappeared into the low-lying clouds, only to return a few seconds later as its motor cut out. The first successful flight was not made until many months later—on another cloudy day so that visual observations were impossible.

The section on post-war work ends with a statement of Professor von Braun's to the effect that, given the resources he had at Peenemunde, he could get a rocket to the Moon in about ten years.

The book concludes with a list of works on astronautics in several languages, and gives a short glossary of terms used in the science. Use of more German words in rocket technology would certainly make for picturesque speech, and it is not surprising that so far only one expression—"Brennschluss"—has been annexed, as being undoubtedly shorter than "moment of fuel cut-off."

Herr Kaiser's book will no doubt do a considerable service in increasing popular interest in rockets, and seems admirably designed to fulfil this purpose.

A. C. C.

Raketen von Stern zu Stern

(By Heinz Gartmann. Illus. by Günter Radke, Lot-Verlag, Worms, Germany. 191 pp.)

This book is in the form of fiction and takes us first of all through the history of rockets up to the present time and then into the future, climaxing with the preparations for a flight into space. The author is a rocket engineer who has worked on rocket development at the German firm of B.M.W. and is an active member of several astronautical societies, including the B.I.S. His description of the history and present achievements in rocketry are sound, as also are his descriptions and analysis of the problems to be overcome before space-flight can be achieved. The whole work is fluently and pleasingly written and can be easily understood by expert and uninitiated alike. Unfortunately, however, the reader who is unacquainted with the subject is also at a disadvantage, as Herr Gartmann goes from hard fact to fiction with no indication of the line of demarcation. This seems to be an inherent disadvantage in this type of exposition, although it would be a considerable improvement if the author could find some way in future editions to indicate where actual achievements end and speculation begins. The illustrations are uneven in quality, some being quite impressive, though at least one is completely lacking in perspective. H. F. Z.

Weltraumflug

(By Professor Dr. Werner Schaub. Dümmlen Verlag, Bonn, Germany. 93 pp., 20 illus.).

This is an excellent introduction for the layman to the pure mechanics of astronautics. Rocket theory and technology are not dealt with, neither are the practical requirements of space-ship design. Within these limitations the author covers his subject clearly and precisely, relegating all mathematical treatment to an appendix. The illustrations are well executed and relevant.

H. F. Z.

Guided Missiles

(By A. R. Weyl, A.F.R.Ae.S. Temple Press, Ltd., Bowling Green Lane, London, E.C.1. 139 pp., illus. 7s. 6d. net.)

This book is intended to give the reader a general picture of the history of guided missiles up to date, and it is written in a style which will appeal to all classes of readers, both the layman, and the technician interested in the historical aspect.

The book is divided into six chapters and has three appendices. The first chapter covers the principles of guided missile propulsion and gives a clear explanation of the various technical terms in common use and the types of power units at present employed. The diverse systems of guidance are discussed, together with a description of the problems associated with launching missiles.

Chapter 2 reviews early ideas and projects, while Chapter 3 continues with the German experiments between the two wars which culminated in the V.1.

A great deal of new material dealing with the development of the V.2 and other German Army and Luftwaffe engineering staffs, makes interesting reading.

Although the experiments with the final version of the V.2 have been described fully by Perring, further information is given in the book which no doubt will be new to many readers. One interesting point is that during the period from the end of 1942 to October, 1944, no less than 12,000 V.2's were constructed.

The development of long-range rockets is dealt with in the next chapter, which also gives a brief history of the rocket. There is included an account of the work done by the late Professor Goddard; other workers, such as H. Oberth, K. Becker, Nebel and Riedel, are discussed at length, together with the research now being conducted at White Sands with the V.2.

The use of peroxide and its applications in modern rocketry are considered, and the chapter closes with an account of the work carried out by the well-known B.M.W. Aero-engine Works at Munich. It was there that research by the chief chemist, Hemesath, established the usefulness of nitric acid as an oxidant.

Chapter 5 gives a full account of all the smaller types of guided missiles of both German and American origin. The only British missile shown is the Fairey "Stooge" ground-to-air missile, used for short-range interception. The final chapter deals with the present and future trends of guided missile research, suggesting various peaceful applications which should be possible in the next decade.

The Appendices are, in the reviewer's opinion, some of the most useful to be found for the student of modern rocketry, giving full information regarding all the known missiles and the code names for various propellants at present in use.

It is unfortunate that probably the most important of all the peaceful applications of the rocket, the Earth Satellite Vehicle, is not mentioned, except in the preface contributed by our Chairman. However, the book can be recommended to those who wish to obtain a clear picture of guided missile progress to date. L. S.

Telescopic Observations of Mars

(By Harold B. Webb. Published by the Author from 145, President Street, Lynbrook, Long Island, N.Y., U.S.A., 1949. 60 pp. $2.50.)

This little book is the result of a lot of hard work on the part of a few amateur astronomers headed by Mr. Webb. It is a record of the observations of this small group at the last four apparitions of Mars.

Some 213 reproductions of drawings made at the telescope form the body of the book and are summarised in four charts on MERCATOR'S projection, with an explanatory chart to each for identification purposes. The printing, which is photostatic, on the first chart, is rather indistinct, and in parts illegible, although the remainder improve considerably.

The observations are also summarised in short terse paragraphs under the headings of the major planetary features, *e.g.* the Polar Caps, *Syrtis Major*, *Sabaeus Sinus*, *Thaumasia*, etc. A brief chapter deals with the colourings observed.

The book concludes with a neat "gadget" for the identification of markings, based on the principle of Phillip's Planisphere. This enables one to identify any object on the meridian providing information is available as to the presence on the meridian of any known feature at an earlier date. Conversely, from the same data, future predictions can be made.

This book tends to fall between two stools. The text is written in a manner suited to the popular reader. On the other hand the subject matter is of prime interest to the aerographer. The danger is that both groups might be disappointed; the one at the superfluity of what can only be for them a series of meaningless "smudges"; the other at the lack of further technical information on, for instance, the changes of colouring, the visibility of the lesser well-known features, etc.

However, it is hoped that both groups will peruse this little book, and that it will stimulate the interest of the popular readers and be of great use to the active observer, particularly for comparing with his own observations.

M. P. D.

The Science of Flight

(By O. G. Sutton, D.Sc., F.R.S. 208 pp., 8 photos., 30 diags. Published Pelican Books, price 1s. 6d.)

The author of this excellent little book occupies the Chair of Mathematical Physics at the Military College of Science, at Shrivenham, and has been Chief Superintendent of the Radar Research and Development Establishment at Malvern. These qualifications make one wonder where he acquired the ability to write so authoritatively on the apparently unrelated subject of aerodynamics, but the point is mentioned only as a tribute to his virtuosity, because he has succeeded brilliantly.

The book is a popular (but not too-popular) account of all aspects of modern aerodynamics—air resistance, wing lift, stability, compressibility and sweepback, supersonic flow, etc. Since so many of the early applications of the rocket are concerned with such matters (and, indeed, even the eventual spaceships will be, when landing back on Earth), this alone would justify our commending the work to B.I.S. members.

However, Chapter VII ("The Ultimate Flying-Machine") has also quite a lot to say about rockets and space-flight, again with a sound discussion of the basic principles involved. It even contains some endorsement (though guarded—"man has conquered the air and may yet win a like dominion over space") of the ambitions of this Society.

A. V. C.

L'Astronautique

(By Lionel Laming. Presses Universitaires de France, 108, Boulevard Saint-Germain, Paris, 110 pp. 1950.)

This little book—the third to bear this title!—is a good popular introduction to the subject. It deals briefly but accurately with rocket principles, atomic energy, navigation, physiological problems, and the solar system. The concluding chapter discusses some of the applications of astronautics, and there is an interesting glossary.

A. C. C.

The Face of the Moon

(By Ralph B. Baldwin. University of Chicago Press, 5750 Ellis Avenue, Chicago 37, Ill., U.S.A. 1949. 237 pp., illus. $5.00.)

Though the surface features of the Moon are generally assumed to be volcanic in origin, there are still some who attribute the craters and "seas" to the impacts of meteorites. This book is certainly the best so far written in support of the latter theory, though most practical observers will undoubtedly regard it in the light of a creditable attempt to bolster up a disreputable hypothesis.

Starting with a brief survey of the history of lunar observation, the writer outlines the main types of formations found upon the Moon's bleak face, and then (Chapter III) discusses the various theories propounded to account for them. Terrestrial meteorite craters are next dealt with, and an effort made to correlate them to lunar ones. There is also a chapter on the Moon's atmosphere, and a summary of current ideas as to the past history of our satellite.

The book should certainly be added to the library of any lunar or interplanetary student, as it contains an enormous amount of valuable information. The print is good; there are a number of photographs fairly satisfactorily reproduced (including one of the Arizona Meteor Crater, looking as unlike a lunar form as could possibly be imagined!) and a rough map in four quadrants. At the same time, few of those who work with a telescope, and are not guided solely by theory, will be disposed to accept Mr. Baldwin's opinions. For instance, the extraordinary statement is made (p. 36) that the lunar craters are distributed "essentially at random," the great chains such as that including Langrenus, Vendelinus and Petavius, being attributed mainly to lighting effects (p. 159). Even a glance at a reliable map will show that this is not so. Moreover, the writer's theory breaks down completely for chains of Theophilus-Cyrillus-Catharina type. He claims that these three objects are of widely different ages (which may well be the case), yet is it likely that three disassociated meteors of almost identical size would strike the Moon in a row and produce the striking group observed? This is stretching coincidence too far.

None of the objections to Spurr's volcanic theory, outlined on page 58, are valid, as is at once evident from a close study of the four volumes produced by that writer. For instance, it is stated that large objects like Pythagoras were formed "long after surrounding smaller objects." This is highly unlikely, however, as it is a fundamental law of crater distribution that smaller craters intrude upon larger ones, never the reverse. Such a law is difficult to explain by any impact theory, but for the domes and the small chain-craters even Mr. Baldwin is reduced to introducing vulcanism, thus placing the chain-craters in a basically different category from all other lunar formations—a totally unjustifiable assumption. Great stress is laid upon the difference between terrestrial volcanoes and lunar ones, but it is overlooked that the difference between our mountains and those of the Moon is just as marked. No explanation is given of the rare lava-filled craters of the Wargentin type, and the minute craterlets found on the tops of certain central peaks (*e.g.* that of Plinius) are attributed to pure chance.

However, the book is pleasingly free from actual misprints (though the names of Peal and Very are wrongly spelt, and those eminently British astronomers, Nasmyth and Carpenter, referred to as "American"), and much of the statistical information, which can be called in to support either the volcanic or the meteoric theory, is of immense value. Special mention should be made of the invaluable list of references, probably the best that has yet been published. As to the actual nature of the lunar craters—surely it will eventually fall to the lot of pioneers from our own Society to have the last word?

P. A. M.

Short-wave Radio and the Ionosphere

(By T. W. Bennington. 138 pp., 61 illus. Iliffe & Sons. 1950. 10s. 6d.)

This book provides an excellent introduction, almost from first principles, to the nature and behaviour of the ionosphere, as it has been determined by radio-wave observations. It uses no mathematics and presents a great deal of information in the form of clear and simple diagrams. Although the emphasis is on the use of the ionosphere for communication purposes, the book will be of value to those with astronomical and geophysical interests—and to those who wish to understand the results of modern rocket research in this region.

A. C. C.

CORRESPONDENCE

The Aphrodite Project

SIR,

As author of "The Aphrodite Project," I was naturally amused by the note in the November, 1949, issue of the B.I.S., entitled "Our Long-suffering Secretary."

"The Aphrodite Project" was written without any deliberate intention of making it a hoax, as I assumed that the readers of *Astounding Science Fiction* were far too knowing to fall for a yarn of this kind. It had so many holes in it I never supposed anyone would take it seriously.

Imagine my surprise when the Office of Public Relations at the California Institute of Technology ("Cal-Tech") told me that the Associated Press had called wanting to know why they had been holding out on them all this time. Later Mr. Campbell, editor of *A.S.F.*, wrote me that he had received so many queries, he had been forced to get out printed forms to answer them.

Most notable feature of the response was the large number of letters from students doing advanced scientific work and technicians in commercial laboratories. (I got one letter from a student at Harvard, who wanted to know how he could get a copy of the 320-page government report.) At least they took the story seriously enough to want to check on it. My feeling is that while people may ridicule the ideas of interplanetary flight, still they aren't quite sure. The atomic bomb and radar contact with the Moon have made anything seem possible.

In fact, I am beginning to be half-way convinced about the feasibility of the Aphrodite Project myself. According to a recent statement by three members

of the staff* of the jet propulsion laboratory at Cal-Tech, it "seems quite feasible from the engineering standpoint to design and construct (multiple step) rockets that are capable of escaping from the gravitational field of the Earth." When we do get around to shooting an unmanned rocket into space, why not do something useful with it? I can't see that aiming for the Moon would serve any particular useful purpose—we know what's on the Moon already. But if an object could be placed near Venus bright enough to be observed it would be of considerable astronomical value.

"PHILIP LATHAM."

* Seifert, Mills, and Summerfield, *American Journal of Physics*, **15**, 255, 1947. "Physics of Rockets: Dynamics of Long Range Rockets."

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